PB82-111469

Airborne Radioactive Emission Control Technology
Volume I

Dames and Moore
White Plains, NY

Prepared for

Office of Radiation Programs
Washington, DC

Mar 80

U.S. Department of Commerce
National Technical Information Service
NTIS

BIBLIOGRAPHIC DATA SHEET	**1. Report No.** ORP Contract Report 81-5A	**2.**	**3. Recipient's Accession No.** PB82 111469

4. Title and Subtitle

Airborne Radioactive Emission Control Technology
Vol . 1

5. Report Date
March 1980

6. U272023

7. Author(s)
Skoski, L., Berlin, R., Oztunali, O., Re, G., et al

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Dames & Moore
20 Haarlem Avenue
White Plains, New York 10603

10. Project/Task/Work Unit No.

11. Contract/Grant No.
68-01-4992

12. Sponsoring Organization Name and Address

Office of Radiation Programs
U.S. Environmental Protection Agency
401 M. St. SW
Washington, D.C. 20460

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstracts

This report reviews the current and future control technology for airborne emissions from a wide variety of industries/facilities, including uranium mining and milling, other nuclear fuel cycle facilities, other NRC-licensed and DOE facilities, fossil fuel facilities, selected metal and non-metal extraction industries, and others. Where specific radioactivity control technology is lacking, a description of any existing control technology is given. Future control technology is assessed in terms of improvements to equipment performance and process alterations. A catalogue of investigated research on advanced control technologies is presented.

17. Key Words and Document Analysis. 17a. Descriptors

Airborne radioactivity source terms
control technology effectiveness
control technology costs
effluent system designs
research and development

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement Release Unlimited	**19. Security Class (This Report)** UNCLASSIFIED	**21. No. of Pages**
	20. Security Class (This Page) UNCLASSIFIED	**22. Price**

1 (a)

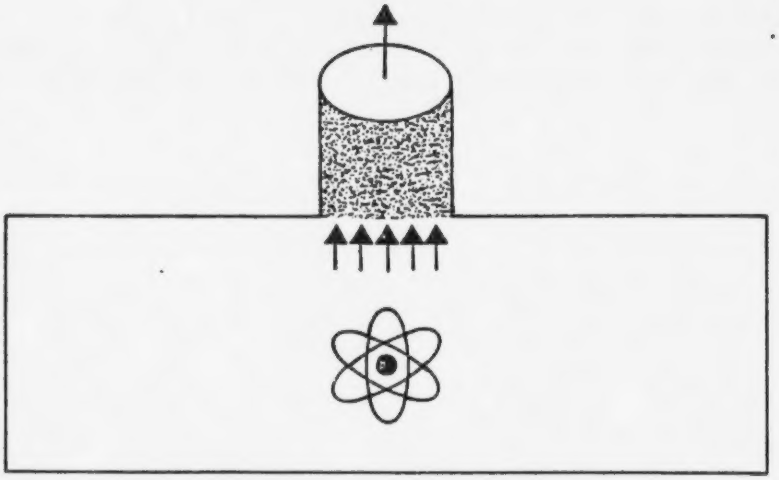
PB82-111469

ORP Contract
Report 81-5A

AIRBORNE RADIOACTIVE EMISSION CONTROL TECHNOLOGY

VOLUME I

DAMES & MOORE
WHITE PLAINS N.Y



TECHNOLOGY ASSESSMENT DIVISION
OFFICE OF RADIATION PROGRAMS
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

NOTICE

This report was prepared by Dames & Moore for the United States Environmental Protection Agency's Office of Radiation Programs (ORP) under Contract No. 68-01-4992. ORP has reviewed it, and the contractor has responded to our comments. We are publishing this report because of its useful information. We have not verified all of the results ourselves, however; nor have we applied our own editorial standards to the text. ORP does not necessarily publish all of the contractor reports it receives.

AIRBORNE RADIOACTIVE EMISSION CONTROL TECHNOLOGY

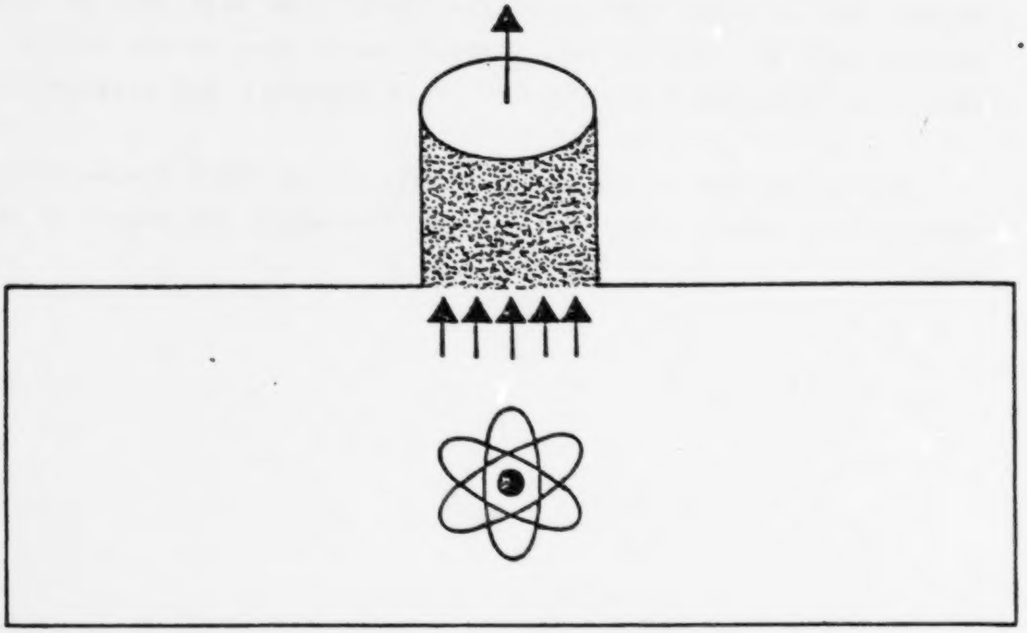
VOLUME I

BY

L. SKOSKI
R. BERLIN
D. CORBY
J. CLANCY
G. HOOPES
J. ISAACS
A. NUGENT
O. OZTUNALI
G. RÉ
J. TAPPEN
H. TUCHFELD

DAMES & MOORE
WHITE PLAINS N.Y.

CONTRACT NO. 68-01-4992



PROJECT OFFICER
J. GRUHLKE

TECHNOLOGY ASSESSMENT DIVISION
OFFICE OF RADIATION PROGRAMS
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

i(h

ACKNOWLEDGEMENTS

The authors wish to express their thanks to the Project Officer, Mr. Jim Gruhlke of the Office of Radiation Programs, U.S. EPA, for his support and guidance throughout the study. We also wish to thank Messrs. Mark M. Gottlieb and Charles Amato also of the office of Radiation Programs U.S. EPA for their comments and suggestions.

Lastly, we wish to thank the members of the White Plains Office, especially C. Jandly, for their support throughout the course of this study.

TABLE OF CONTENTS

Chapter ... Page

CHAPTER I: Introduction and Conclusions ... I.1-1

CHAPTER II: Current Control Technologies - by Industry/Facility ... II.1-1

- Section 1: Introduction ... II.1-1
- Section 2: The Uranium Mining and Milling Industry ... II.2-1
- Section 3: Other Nuclear Fuel Cycle Facilities ... II.3-1
- Section 4: Other NRC-Licensed and DOE Facilities ... II.4-1
- Section 5: Fossil Fuels ... II.5-1
- Section 6: Selected Metal and Non-Metal Extraction Industries ... II.6-1
- Section 7: Selected Non-Nuclear Facilities ... II.7-1

Appendices: ... II A-1

CHAPTER III: Current Control Technologies - by Isotope ... III.1-1

CHAPTER IV: Advanced Control Technologies ... IV.1-1

- Section 1: Introduction ... IV.1-1
- Section 2: Available But Not Yet Applied Control Technologies for Uranium Mines and Mills ... IV.2-1
- Section 3: Conceptual But Not Yet Demonstrated Control Technologies Applicable to Uranium Mines and Mills ... IV.3-1
- Section 4: Future Control Technologies for Gaseous Radionuclide Releases ... IV.4-1
- Section 5: Novel Particulate Control Devices ... IV.5-1

Appendices: ... IV A-1

CHAPTER V: Radiopharmaceutical Users ... V.1-1

Appendix: ... V A-1

CHAPTER 1

Introduction and Conclusions

TABLE OF CONTENTS

Page

Foreword....................I.1-1
Introduction....................I.1-1
Background....................I.1-1
Objective....................I.1-2
Report Organization....................I.1-2
General Methodology....................I.1-4
Data Aquisition....................I.1-6
Conclusions....................I.1-6

LIST OF TABLES

Table Page

1-1 Sources of Data....................I.1-7

CHAPTER II

Current Control Technologies - by Industry/Facility

TABLE OF CONTENTS

Page

Section 1: Introduction....................................II.1-1

Background....................................II.1-1
Outline....................................II.1-3

Section 2: The Uranium Mining and Milling Industry............II.2-1

Background....................................II.2-1
Data Acquisition....................................II.2-1
Industry Profile....................................II.2-2
Radioactivity of Uranium Ore....................II.2-4
Uranium Mining....................................II.2-4
   Mining Methodologies..........................II.2-4
   Current Control Technology in Uranium Mining...II.2-10
Uranium Milling....................................II.2-12
   Uranium Ore Processing........................II.2-12
   Radionuclide Emissions from Uranium Mills......II.2-22
   Current Control Technology in Uranium Milling .II.2-24
   Control Technology Costs......................II.2-33
Summary....................................II.2-37
Conclusions....................................II.2-40
References....................................II.2-41

Section 3: Other Nuclear Fuel Cycle Facilities................II.3-1

Background....................................II.3-1
Uranium Conversion Plants........................II.3-13
Gaseous Diffusion (Enrichment) Plants............II.3-24
   Oak Ridge Gaseous Diffusion Plant (ORGDP)......II.3-25
   Portsmouth Gaseous Diffusion Plant
      Portsmouth, Ohio.....................II.3-26
   Paducah Gaseous Diffusion Plant
      Paducah, Kentucky....................II.3-31
Fuel Fabrication Facilities......................II.3-32
   LWR Fuel Fabrication Plants....................II.3-32
   Non-LWR Fuel Fabrication Plants................II.3-57
Central Station Nuclear Power Plants..............II.3-61
   Boiling Water Reactors........................II.3-61
   Pressurized Water Reactors....................II.3-72
   Other Central Station Nuclear Power Plants.....II.3-78

CHAPTER II

Current Control Technologies - by Industry/Facility (cont'd)

Page

Section 3: Fuel Reprocessing Facilities.........................II.3-82
  LWR Fuel Reprocessing Facilities..............II.3-82
  HTGR Fuel Reprocessing Facilities.............II.3-89
 Waste Management Facilities.......................II.3-97
  Spent Fuel Storage Facilities...................II.3-97
  Waste Incinerators.................................II.3-98
  Waste Solidification Facilities..................II.3-99
  Shallow-Land Burial Facilities...................II.3-99
 References...II.3-101

Section 4: Other NRC-Licensed and DOE Facilities..............II.4-1

 Reactors..II.4-1
 Other Special Nuclear Material and Source Material Licensees.............................II.4-6
 By-Product Material Licensees.....................II.4-12
  Academic By-Product Material Licensees.........II.4-13
  Industrial By-Product Material Licensees.......II.4-13
  Medical By-Product Material Licensees..........II.4-17
 High Energy Accelerators............................II.4-24
  Alternating Gradient Synchrotron (AGS) Brookhaven National Laboratory (BNL)...........II.4-25
  Fermilab Accelerator, Batavia, Illinois........II.4-25
  Stanford Linear Accelerator (SLAC), Stanford University....................II.4-25
  Positron-Electron Storage Ring Project (PEP), Stanford University....................II.4-27
  Isabelle Facility, Brookhaven National Laboratory..................................II.4-27
 Fusion Energy Devices................................II.4-28
 Weapons Production Facilities.......................II.4-32
  Mound Laboratory - Miamisburg, Ohio............II.4-32
  Pantex Plant - Amarillo, Texas...................II.4-32
  Pinellas Plant - St. Petersburg, Florida.......II.4-33
  Rocky Flats Plant - Jefferson County, Colorado.II.4-33
 National Laboratories..................................II.4-34
  Idaho National Engineering Laboratory (INEL)...II.4-34
  Hanford Reservation - Richland, Washington.....II.4-52
  Brookhaven National Laboratory (BNL), NY.......II.4-54
  Battelle Columbus Laboratories Columbus, Ohio.........................II.4-56
  Los Alamos Scientific Laboratory (LASL), New Mexico............................II.4-56
 References...II.4-66

CHAPTER II

Current Control Technologies - by Industry/Facility (cont'd)

Page

Section 5: Fossil Fuels....................II.5-1

Introduction....................II.5-1
  Purpose of Study....................II.5-1
  Organization....................II.5-2
  Standards....................II.5-3
  Data Acquisition....................II.5-4
Coal Extraction, Transport and Storage....................II.5-5
  Industry Description....................II.5-5
  Geology....................II.5-11
  Particulate Emissions and Controls....................II.5-11
Radionuclides in Coal and its Combustion Products.II.5-22
  General....................II.5-22
  Western vs. Eastern Coal....................II.5-25
  Heating Value vs. Radionuclide Release....................II.5-25
  Coal and Ash-Radionuclide Studies....................II.5-28
  Summary....................II.5-36
Radionuclides and Control Devices - Natural Gas and Fuel Oil Fired Electric Generating Plants....................II.5-39
  Natural Gas....................II.5-39
  Fuel Oil....................II.5-39
Particulate Control Device Evaluation - Electric Generating Stations....................II.5-43
  Introduction....................II.5-43
  Particulate Collection Efficiencies....................II.5-45
  Costs....................II.5-58
  Energy Use....................II.5-90
  Residuals....................II.5-96
Fossil Fuels - Power Plant Survey....................II.5-102
  Background....................II.5-102
  Control Device Utilization....................II.5-102
  Control Device Evaluation....................II.5-104
  Comparison of Survey and Literature Data....................II.5-108
References....................II.5-110

Section 6: Selected Metal and Non-Metal Extraction Industries..II.6-1

Background....................II.6-1
  Industry Selection....................II.6-1
  Industry Size....................II.6-2
  Radionuclide Association....................II.6-2
  Data Acquisition....................II.6-2
  Industry Description....................II.6-5
  Ore Geology and Radionuclide Content....................II.6-5

Current Control Technologies - by Industry/Facility
(cont'd)

Page

Section 6
Process Description....................................II.6-5
Airborne Radionuclide or Particulate Emissions.II.6-6
Airborne Radionuclide or Particulate Emission Controls....................................II.6-6

Crushed Stone Industry..............................II.6-7
Industry Description..............................II.6-7
Geology and Radionuclide Content...............II.6-9
Process Description...............................II.6-14
Airborne Radionuclide or Particulate Emissions.II.6-14
Airborne Radionuclide or Particulate Emission Controls....................................II.6-23

The Iron Industry....................................II.6-27
A. Iron Ore...II.6-27
Industry Description...................II.6-27
Ore Geology and Radionuclide Content....II.6-28
Process Description....................II.6-31
Airborne Particulate Releases...........II.6-35
Airborne Radionuclide or Particulate Emissions and Controls.................II.6-38
B. Iron and Steel...................................II.6-44
Industry Description...................II.6-44
Process Description....................II.6-47
Airborne Radionuclide or Particulate Emissions and Controls.................II.6-49

The Fluorspar Industry..............................II.6-65
Industry Description..............................II.6-65
Ore Geology and Radionuclide Content...........II.6-67
Process Description...............................II.6-69
Airborne Radionuclide or Particulate Emissions.II.6-73
Airborne Radionuclide or Particulate Emission Controls....................................II.6-77

The Phoshpate Industry..............................II.6-81
Industry Description..............................II.6-81
Ore Geology and Radionuclide Content...........II.6-85
Process Description...............................II.6-88
Airborne Radionuclide Emissions.................II.6-94
Airborne Radionuclide or Particulate Emission Controls....................................II.6-110

Current Control Technologies - by Industry/Facility (cont'd)

Page

Section 6: The Bauxite Industry....II.6-118
  Industry Description....II.6-118
  Ore Geology and Radionuclide Content....II.6-120
  Process Description....II.6-123
  Airborne Radionuclide or Particulate Emissions.II.6-127
  Airborne Radionuclide or Particulate Emission Controls....II.6-131

The Copper Industry....II.6-133
  Industry Description....II.6-133
  Ore Geology and Radionuclide Content....II.6-135
  Ore Processing Description....II.6-138
  Airborne Radionuclide or Particulate Emissions.II.6-159
  Radon Releases....II.6-164
  Airborne Radionuclide or Particulate Emission Controls....II.6-165
  Radon Controls....II.6-175

References....II.6-177

Section 7: Selected Non-Nuclear Facilities....II.7-1

Geothermal Power Production....II.7-1
  Industry Description....II.7-1
  Radionuclide Sources....II.7-4
  Emission Controls....II.7-8
  Summary and Conclusions....II.7-8

Ground Water Treatment Plants....II.7-10
  Radon in Ground Water....II.7-10
  Control of Airborne Emissions....II.7-12
  Conclusion....II.7-12

References....II.7-14

CHAPTER II

Current Control Technologies - by Industry/Facility

LIST OF TABLES

Table		Page
1-1	Review of Individual Sections	II.1-2
2-1	U.S. Uranium Ore Processing Mills Operating in 1978	II.2-5
2-2	Uranium-238 Principal Decay Modes	II-2-8
2-3	Uranium Mill Activity Emission Rates	II.2-23
2-4	Uranium Mill Control Technology Summary	II.2-25
2-5	Dryer Emission Control Technology	II.2-30
2-6	Packaging Area Control Technology	II.2-32
2-7	Bag-House Collector Cost Summary	II.2-35
2-8	Wet Scrubber Cost Summary	II.2-38
3-1	Classification of Isotopes According to Relative Radiotoxicity Based on Inhalation Hazard Amounts (Ci) Equivalent to 1 g of Pu-239 (HEP)	II.3-4
3-2	Hazard Classification of Radioisotopes	II.3-5
3-3	Zoning of Facilities Based on Radiotoxicity of Materials Handled	II.3-5
3-4	Design Efficiency Values for Single-Pass Impregnated Charcoal Filter	II.3-12
3-5	Summary of Control Technologies Employed at Commercial UF_6 Conversion Facilities	II.3-16
3-6	Efficiency of Wet Dust Collectors	II.3-20
3-7	Efficiency of Noxious Gas Absorbers	II.3-21
3-8	Summary of Gaseous and Airborne Radwaste Treatment Variables for the Model 10,000 metric-ton/year Dry Process UF_6 Conversion Plant	II.3-22
3-9	Estimated Capital and Annual Costs (1978 Dollars) in Addition to the Base Case (Case 1) for the 10,000 metric-ton/year Model Dry Process UF_6 Conversion Plant	II.3-23
3-10	LWR Fuel Fabrication Plants	II.3-33
3-11	Other Fuel Fabrication Plants	II.3-34
3-12	Gaseous Effluent from the Low Enriched Uranium Oxide Facility, Building 301	II.3-43
3-13	Gaseous Effluents from Finished Product Fabrication, Building 302-3	II.3-47
3-14	Gaseous Effluents from Building 234 (Plutonium Fuel Fabrication Facility)	II.3-49
3-15	ADU Process Model Fuel Fabrication Plant (1500 MTU/yr) Gaseous Waste Treatment Data	II.3-52
3-16	DC Process Model Fuel Fabrication Plant (1500 MTU/yr) Gaseous Waste Treatment Data	II.3-58
3-17	Model Mixed Oxide Fuel Fabrication Plant (1500 MTU/yr) Gaseous Waste Treatment Data	II.3-59

CHAPTER II

Current Control Technologies - by Industry/Facility

LIST OF TABLES
(cont'd)

Table		Page
3-18	Summary of Control Technologies for BWRs Considered	II.3-64
3-19	Summary of Annual Costs Applicable to Control of Noble Gases and Iodine Emissions from 2400 MW(e) BWR Stations	II.3-70
3-20	Summary of Control Technologies for PWRs Considered	II.3-75
3-21	Summary of Annual Costs Applicable to Control of Noble Gases and Iodine Emissions from 2400 MW(e) PWR Stations	II.3-76
3-22	Average Fuel Activity and Release Rates at a Model LWR Reprocessing Plant	II.3-86
3-23	Capital and Annual Costs (1978 Dollars) in Addition to the Base Case for Airborne Effluent Control Technologies at a Model LWR Reprocessing Plant	II.3-90
3-24	Decontamination Factors and Annual Releases for the Model HTGR Reprocessing Plant with Case 1 Airborne Effluent Control Technology	II.3-96
4-1	Control Technologies Utilized for Reduction of Routine Airborne Radionuclide Emissions at Research and Test Reactors	II.4-3
4-2	Control Technologies Employed by Special Nuclear Material Licensees in Reducing Routine Airborne Radionuclide Releases	II.4-7
4-3	Control Technologies Employed by Source Material Licensees in Reducing Routine Airborne Radionuclide Releases	II.4-10
4-4	Academic By-Product Material Licensees	II.4-14
4-5	Industrial By-Product Material Licensees	II.4-18
4-6	Medical By-Product Material Licensees	II.4-22
4-7	Test Reactor Area Airborne Waste Summary for 1974	II.4-37
4-8	Estimated Airborne Radioactivity Releases from LOFT Experiments	II.4-38
4-9	Postulated Annual Releases of Radioactive Gases From Power Burst Facility	II.4-40
5-1	U.S. Coal Resources and Reserves	II.5-7
5-2	Coal Industry - Productivity and Mining Trends	II.5-9
5-3	Future Coal Production Scenarios	II.5-10
5-4	Contribution to Respirable Mining Dust Emissions from Each Source Within the Mine	II.5-13
5-5	Coal Particulate Emissions from Unit Train 985 KM (612 Mi) Round Trip	II.5-16

CHAPTER II

Current Control Technologies - by Industry/Facility

LIST OF TABLES
(cont'd)

Table Page

5-6 Coal Particulate Emissions from Barge Transport of Coal....II.5-18
5-7 Coal Particulate Emissions from Truck Transport of Coal - 20 Mile Haul....II.5-20
5-8 Uranium, Thorium, and Potassium Concentrations in Coal as Mined....II.5-23
5-9 Radioactivity in Ash Samples Collected from Power Plants in the U.S....II.5-24
5-10 Coal Heat Content....II.5-27
5-11 Selected Trace Element Flows Through a Coal-Fired Power Plant....II.5-29
5-12 Contents of Various Radionuclides in Coal, Bottom Ash, and Fly Ash....II.5-32
5-13 Radionuclide Enrichment Factors Relative to Input Coal and Normalized to K-40....II.5-34
5-14 Radiochemical Analysis of Coal and Coal By-Products....II.5-37
5-15 Summary of Data on Difficult Electrostatic Precipitator Control Cases for Pulverized-Coal-Fired Steam Generators....II.5-47
5-16 Summary of Data on Pulverized-Coal-Fired Steam Generator High Efficiency Electrostatic Precipitator Systems....II.5-48
5-17 Summary of Data on Baghouses Applied to Coal-Fired Steam Generator Combustion Gases....II.5-55
5-18 Data on Particulate Scrubbing Systems Installed on Pulverized-Coal-Fired Steam Generators....II.5-57
5-19 Capital Investment Estimate Summary for Base Case System (500 MW Plant)....II.5-62
5-20 Capital Investment Summaries for Alternate Cases: Hot-Side Electrostatic Precipitator....II.5-64
5-21 Capital Investment Summary for Alternate Cases: American-Style Cold-Side Electrostatic Precipitators....II.5-65
5-22 Capital Investment Summaries for Alternate Cases: European-Style Cold-Side Electrostatic Precipitators....II.5-66
5-23 Capital Investment Summaries for Alternate Cases: Fabric Filter....II.5-67
5-24 Calculation of Capital Investment for 500 MW Case Studies....II.5-68
5-25 Cost and Unit Factors for Operation and Maintenance for the 500 MW Base Case Systems....II.5-72
5-26 Details of Base Case Fabric Filter Collector Maintenance Costs....II.5-73
5-27 Summary of Annual Operation and Maintenance Costs for Case Studies....II.5-75

CHAPTER II

Current Control Technologies - by Industry/Facility

LIST OF TABLES
(cont'd)

Table Page

5-28 Model Plant Parameters and Assumptions Used in the Particulate Control Analysis....II.5-78
5-29 Analyses of Coals Used as the Cost Estimating Basis....II.5-79
5-30 Particulate Emission Control Device Design Parameters....II.5-80
5-31 Costs of Particulate Control Alternatives....II.5-81
5-32 Capital Investment and Annual Operating Costs: Fabric Filters....II.5-84
5-33 Wet Scrubbers - Installed Cost....II.5-88
5-34 Power Requirements for Particulate Collection Systems - EPRI Case Studies....II.5-92
5-35 Estimated Power Consumption and Pollution from Particulate Control at 1000 Megawatt Power Plant....II.5-94
5-36 Energy Penalties Associated with Particulate Control Alternatives....II.5-95
5-37 Fly Ash and Bottom Ash Production Rates for Model 1000 Megawatt Power Plants....II.5-100
5-38 Electric Generating Station Survey - Operational Data....II.5-103
5-39 Control Device Efficiencies - Power Plant Survey....II.5-105
5-40 Particulate Control Device Data - Power Plant Survey....II.5-107
5-41 Particulate Control Device Costs - Power Plant Survey....II.5-109

6-1 Material Handled in U.S. Extraction Industries - 1975....II.6-3
6-2 Classes of Stone....II.6-8
6-3 Crushed Stone Sold or Used by Producers in the United States, by Use....II.6-10
6-4 Natural Radionuclides by Rocks....II.6-11
6-5 Radionuclide Content of Selected Granitic and Related Rocks....II.6-12
6-6a Particulate Emissions: Crushed Limestone Industry....II.6-17
6-6b Particulate Emissions: Crushed Granite Industry....II.6-18
6-6c Particulate Emissions: Crushed Sandstone, Quartz and Quartzite Industry....II.6-19
6-6d Particulate Emissions: Other Crushed Stone Industries...II.6-20
6-7 Respirable Particulate Emissions - Crushed Stone Industry....II.6-21
6-8 Crushed Stone Industry - Emission Factors Obtained from Two Studies....II.6-22
6-9 Particulate Control Systems - Costs and Requirements....II.6-25
6-10 Comparison of Two Methods of Dust Control in Stone Crushing Operations....II.6-26
6-11 Chief Iron-Bearing Minerals....II.6-30

CHAPTER II

Current Control Technologies - by Industry/Facility

LIST OF TABLES
(cont'd)

Table		Page
6-12	Point Source Particulate Emissions	II.6-39
6-13	Control Efficiencies for Various Combinations of Control Devices and Sources	II.6-42
6-14A	Selection of Best Emission Factors for Open Dust Sources	II.6-53
6-14B	Nationwide Emissions From Open Dust Sources Based on Best Emission Factors	II.6-55B
6-15	Materials Handling Dust Controls	II.6-57
6-16	Storage Pile Activity Dust Controls	II.6-58
6-17	Road Dust Controls	II.6-59
6-18	Exposed Area Dust Controls	II.6-60
6-19	Blast Furnace and Sinter Machine Emission Factors	II.6-63
6-20	Operating Data - Major Mines and Mills	II.6-71
6-21	Particulate Emissions and Controls - Fluorspar Dryers	II.6-76
6-22	Fluorspar Dryers - Costs for Terminal Control Device	II.6-79
6-23	Central Florida Phosphate Rock Producers	II.6-83
6-24	Idaho Phosphate Mining Operations	II.6-91
6-25	Air Particulate Emissions and Controls - Phosphate Mining and Beneficiation	II.6-96
6-26	Phosphate Rock Drying	II.6-98
6-27	Phosphate Rock Grinding	II.6-100
6-28	Phosphate Rock Transfer	II.6-102
6-29	Phosphate Storage	II.6-104
6-30	Phosphate Loading/Unloading Activities	II.6-105
6-31	Radium-226, Uranium and Thorium Concentrations in Florida Phosphate Mine Products and Wastes	II.6-107
6-32	Radionuclide Content of Selected Idaho Phosphate Samples	II.6-111
6-33	Material and Radionuclide Balance - FMC Plant Calciner	II.6-112
6-34	Particulate Control Technology - Western Region Phosphates	II.6-115
6-35	Uranium and Thorium in Selected Bauxites	II.6-122
6-36	Particulate Emissions and Controls - Bauxite Mining and Processing	II.6-129
6-37	Thorium and Uranium Contents - Input/Output Material from Alumina Production	II.6-130
6-38	Copper Ore Minerals of Economic Interest	II.6-136
6-39	The Uranium Concentrations of Copper Ore from the Kennecott Bingham, Utah Mine	II.6-139
6-40	Average Abundance of Uranium in Porphyry Copper Intrusions and Barren Intrusions of Similar Composition	II.6-140
6-41	Radon-Daughter Sample Concentrations in Underground Copper Mines	II.6-141
6-42	Radiological Analysis of Copper Mine Pumpout Water	II.6-142
6-43	Particulate Controls Employed at Some Domestic Smelters	II.6-146

CHAPTER II

Current Control Technologies - by Industry/Facility

LIST OF TABLES
(cont'd)

Table		Page
6-44	Uranium and Thorium Concentrations of Various Solids at an Operating Reverberatory Furnace	II.6-163
6-45	Controls Utilized for Reducing Routine Airborne Particulate Emissions During the Production of Blister Copper	II.6-166
6-46	Operating Conditions and Cost Estimates for a Copper Roaster Gas Cleaning System Consisting of a Wet Scrubber Followed by a Cooling Chamber and Electrostatic Precipitator	II.6-169
6-47	Operating Conditions and Cost Estimates for an Electrostatic Precipitator Gas Cleaning System for Reverberatory Furnace Off-Gas	II.6-171
6-48	Operating Conditions and Cost Estimates for a Wet Scrubber Gas Cleaning System for Reverberatory Furnace Off-Gas	II.6-172
7-1	Installation Date, Net Electrical Installed Capacity, and Steam Flow Rates at the Geysers, California, Geothermal Power Plant	II.7-5
7-2	Radon Content of Pre-Turbine Steam	II.7-9
7-3	Measured Rn-222 Concentrations in Ground Water Samples	II.7-11

CHAPTER II

Current Control Technologies - by Industry/Facility

LIST OF FIGURES

Figure		Page
2.1	Principal Uranium Deposits of the United States	II.2-3
2.2	The Uranium-238 Decay Series	II.2-7
2.3	Acid Leach Solvent Extraction (SX)	II.2-14
2.4	Acid Leach, Ion Exchange (IX), Precipitation	II.2-15
2.5	Acid Ion Exchange (IX), ELUEX, Precipitation	II.2-16
2.6	Acid Leach, RIP, Precipitation	II.2-17
2.7	Acid Leach, RIP, ELUEX, Precipitation	II.2-18
2.8	Alkaline Leach, Caustic Precipitation	II.2-19
2.9	Alkaline Leach, RIP, Precipitation	II.2-20
2.10	Generalized Uranium Mill Flow Diagram	II.2-21
2.11	Generalized Flow Diagram for Common Yellowcake Emission Control Systems	II.2-29
3.1	The Nuclear Fuel Cycle - Lightwater Reactors	II.3-2
3.2	HEPA Filter Efficiency versus Flow Rate	II.3-9
3.3	UF_6 Conversion Methodologies	II.3-15
3.4	Plant Process Gas Flow	II.3-27
3.5	Typical Heating and Ventilation Systems	II.3-28
3.6	Pneumatic System	II.3-30
3.7	Nominal ADU Process System - 5 MTU/Day	II.3-36
3.8	Nominal DC Process System - 5 MTU/Day	II.3-37
3.9	Low Enriched Uranium Oxide Facility - Building 301	II.3-42
3.10	Highly Enriched Uranium Fuel Fabrication - Buildings 302-303	II.3-44
3.11	Plutonium Fuel Rod Fabrication, Building 234	II.3-48
3.12	DC Radwaste Treatment Systems - DC Process Gaseous Waste - Case 1	II.3-53
3.13	DC Radwaste Treatment Systems - DC Process Gaseous Waste - Case 2	II.3-54
3.14	DC Radwaste Treatment Systems - DC Process Gaseous Waste - Case 3	II.3-55
3.15	DC Radwaste Treatment Systems - DC Process Gaseous Waste - Case 4	II.3-56
3.16	Liquid and Gaseous Radwaste Effluents from Boiling Water Reactors	II.3-63
3.17	Catalytic Recombiner - Ambient Temperature Charcoal Adsorber System	II.3-66
3.18	Low Temperature Charcoal Adsorber System	II.3-68
3.19	Liquid and Gaseous Radwaste Effluents from Pressurized Water Reactors	II.3-73
3.20	Schematic of HTGR	II.3-79
3.21	Schematic of LMFBR Steam Supply System	II.3-79
3.22	Barnwell Nuclear	II.3-84
3.23	Model Fuel Reprocessing Plant: Case 1	II.3-88
3.24	Summary Diagram of Fuel Flow in the HTGR Cycle	II.3-92
3.25	Model Fuel Reprocessing Plant: Case 1 - Base Case	II.3-94

LIST OF FIGURES
(cont'd)

Figure Page

4.1 BNL Alternating Gradient Synchrotron and Related Facilities........II.4-26
4.2 ICPP Airborne Waste System........II.4-42
4.3 Atmospheric Protection System........II.4-43
4.4 WCF Schematic Flowsheet........II.4-45
4.5 EBR II Radioactive Airborne Waste System - Reactor Plant.II.4-47
4.6 HFEF - S Ventilation Flow Diagram........II.4-49
4.7 HFEF - N Cell Ventilation System........II.4-50
4.8 (A,B) Glove Box Filter........II.4-58
4.9 (A-E) Process Exhaust Gas Filter System........II.4-60
4.10 (A-E) Room Air Filter System........II.4-62

5.1 Fractional Efficiency Curve Calculated from Inlet and Outlet Size Distribution for an Electrostatic Precipitator Collecting Oil Ash........II.5-41
5.2 Particle-Size Distribution: ESP Effluent from Fuel Oil Ash Collection........II.5-42
5.3 Emission Test Data for Electrostatic Precipitators (Coal-Fired Steam Generators)........II.5-46
5.4 Typical Fractional Efficiencies for Existing Collectors..II.5-51
5.5 Levelized Revenue Requirements for Collection Systems....II.5-59
5.6 Estimated Capital Investment for Collection Systems......II.5-70
5.7 Scrubber Prices - Carbon Steel 3/4" Plate........II.5-87
5.8 Bottom Ash Generation for Coal-Fired Boilers........II.5-98
5.9 Fly Ash Generation for Coal-Fired Boilers........II.5-99

6.1 Production of Crushed Stone........II.6-15
6.2 Flow Diagram: Iron Ore Mining, Beneficiation, and Agglomeration........II.6-29
6.3 Air Particulate Emission Points - Taconite Ore Mining and Beneficiation........II.6-32
6.4 Pelletizer Flowchart........II.6-34
6.5 General Flow Diagram for the Iron and Steel Industry.....II.6-45
6.6 1976 Iron and Steel Industry Material Flows........II.6-46
6.7 Iron and Steel Raw Material Storage Pile Activities......II.6-48
6.8 Typical Sinter Plant Flow Diagram for Superfluxed Sinter.II.6-50
6.9 Blast Furnace Plant with Auxilary Equipment........II.6-51
6.10 Fluorspar Processing Flowsheet........II.6-70
6.11 Phosphate Industry - Supply and Demand in 1975........II.6-84
6.12 Idaho Phosphates - Mining and Processing........II.6-93
6.13 Southeastern Region - Phosphate Mining and Processing....II.6-95
6.14 Alumina Industry........II.6-119

CHAPTER II

Current Control Technologies - by Industry/Facility

LIST OF FIGURES
(cont'd)

Figure Page

6.15 Flowsheet - The Production of Alumina from Bauxite.......II.6-124
6.16 Copper Production Process..............................II.6-134
6.17 Multi-Hearth Roaster...................................II.6-153
6.18 Fluidization-Bed Roaster...............................II.6-154
6.19 Reverberatory Smelting Furnace.........................II.6-156
6.20 Electric Smelting Furnace..............................II.6-157
6.21 Outokumpu Flash Furnace................................II.6-157
6.22 Noranda Furnace..II.6-160

7.1 General Area Map of Part of Northern California Indicating the Location of the Geysers Geothermal Field..II.7-2
7.2 Map of the Geysers Area................................II.7-3
7.3 Schematic Diagram of the Typical System at the Geysers...II.7-6
7.4 General Geothermal Power Cycle.........................II.7-7

CHAPTER II

Appendices

TABLE OF CONTENTS

Page

Appendix IIA: Sample HEPA System Costs and Specifications......IIA-1

Introduction....................................IIA-1
Background......................................IIA-1
HEPA System Components and Unit Costs...........IIA-4
Sample HEPA System and Costs....................IIA-11
    Capital Costs...............................IIA-13
    Annual Costs................................IIA-15
Sample HEPA Specification.......................IIA-17
References......................................IIA-33

Appendix IIB: Particulate Control Technologies................IIB-1

Introduction....................................IIB-1
Electrostatic Precipitators.....................IIB-1
    Description.................................IIB-1
    Corona Generation...........................IIB-3
    Dust Effects on Corona Generation...........IIB-7
    Particle Charging...........................IIB-10
    Dust Resistivity............................IIB-12
    Efficiency Determination....................IIB-14
    Dust Removal................................IIB-16
    Types of Electrostatic Precipitators........IIB-17
    General Advantages and Disadvantages........IIB-18
    Specifications to Meet Standards............IIB-19
Fabric Filters (Baghouses)......................IIB-22
    General Description.........................IIB-22
    Operating Principles........................IIB-24
    Particulate Collection Efficiency...........IIB-29
    Advantages and Disadvantages................IIB-31
Wet Scrubbers...................................IIB-33
    Description.................................IIB-33
    Particulate Collection Efficiency...........IIB-36
References......................................IIB-38

Appendix IIC: Geysers Monitoring Program......................IIC-1

Introduction....................................IIC-1
Measurements of Radon Emissions.................IIC-1
    Rn-222 Emissions from the Geysers Power Plant.......IIC-1
    Rates of Rn-222 Exhalation from Soil........IIC-2
    Rate of Rn-222 Emissions from a Fumarole.....IIC-2

CHAPTER II

Appendices

TABLE OF CONTENTS
(cont'd)

Page

Appendix IIC: Measurements of Rn-222 and Short-Lived Radon Daughter Concentrations....................IIC-3
  Short-Term (5 min.) Measurements.............IIC-3
  Long-Term (1 week) Measurements..............IIC-4
  Uncombined Fraction of Short-Lived Radon Daughters.............................IIC-4
  Radon-222 Concentrations in Air..............IIC-5
Measurements of Long-Lived Radon Daughter (Pb-210) and Other Radionuclides in Air..........IIC-5
  Mass, Pb-210, and Th-230 Concentrations in Air and Their Distribution with Particle Size..............................IIC-5
  Concentration of Pb-210 and Gamma-Emitting Radionuclides in Air.........................IIC-6
Concentration of Pb-210 in Vegetation............IIC-6
Concentration of Ra-226 and Pb-210 in Water and Steam Condensate............................IIC-7
Concentration of Gamma-Emitting Radionuclides in Soil and Terrestrial Gamma Exposure Rates.....IIC-7
Total External Gamma Exposure....................IIC-9
Concentration of Pb-210 and Gamma-Emitting Radionuclides in Cooling Tower Sludge and Stretford Sulfur Product..........................IIC-9
References.......................................IIC-11

CHAPTER II

Appendices

LIST OF TABLES

Table — Page

A-1 Standard HEPA Filter Sizes....IIA-3
A-2 Relative Costs of HEPA Filters....IIA-3
A-3 Standard HEPA Filter Costs....IIA-6

C-1 The Range of Concentration of Naturally Occuring Radionuclides in Soil and of the External Exposure Rate Due to These Terrestrial Sources....IIC-8

CHAPTER II

Appendices

LIST OF FIGURES

Figure Page

A.1 Basic HEPA System and Components..........IIA-5
A-2 HEPA Filter vs. System Characteristics..........IIA-8
A.3 Purchase Price of Dampers and Drives as a Function of Damper Diameter..........IIA-9
A.4 Damper Prices vs. Diameter..........IIA-10
A.5 Sample HEPA Filter System..........IIA-12

B.1 Typical Fabric Filter Arrangement..........IIB-27

CHAPTER III

Current Control Technologies - By Isotope

TABLE OF CONTENTS

Page

Introduction..III.1-1
Background..III.1-2
Particulates..III.1-4
    Uranium, Thorium, and Their Particulate Daughters..........III.1-6
    Transuranic Particulates..................................III.1-13
    Other Particulates..III.1-15
Gases...III.1-15
    Radon and Thoron..III.1-19
    Noble Gases...III.1-20
    Halogens..III.1-22
    Other Gases...III.1-24
References..III.1-26

CHAPTER III

Current Control Technologies - By Isotope

LIST OF TABLES

Table		Page
1-1	Uranium-238 Decay Series Radionuclides	III.1-7
1-2	Uranium-235 Decay Series Radionuclides	III.1-8
1-3	Thorium-232 Decay Series Radionuclides	III.1-9
1-4	Relatively Long-Lived Transuranic Isotopes	III.1-14
1-5	Major Long-Lived Fission and Activation Products	III.1-16
1-6	Major Noble Gas Radioisotopes	III.1-21
1-7	Major Halogen Radioisotopes	III.1-23
1-8	Other Major Radioactive Gases	III.1-25

CHAPTER IV

Advanced Control Technologies

TABLE OF CONTENTS

Page

Section 1: Introduction....................................IV.1-1

Section 2: Available But Not Yet Applied Control Technologies for Uranium Mines and Mills....................................IV.2-1

Uranium Mines....................................IV.2-1
  Engineered Systems of Effluent Reduction........IV.2-1
  Uranium Mine Atmospheric Control Technology.....IV.2-2
  Electronic Air Cleaning Systems................IV.2-3
  Filtration......................................IV.2-4
  Process Improvements............................IV.2-7
Uranium Mills.....................................IV.2-8
  Process Improvements............................IV.2-8
  Tailings Control Technologies...................IV.2-9
  Currently Proposed Tailings Disposal/ Reclamation Alternatives......................IV.2-11
Conclusion..IV.2-14
References..IV.2-15

Section 3: Conceptual But Not Demonstrated Control Technologies Applicable to Uranium Mines and Mills..IV.3-1

Introduction......................................IV.3-1
Radon-222 Control Technology - Mine Effluents.......IV.3-1
  Radon-222 Emanation Reduction by Polymeric Sealants..IV.3-2
  Systems for Removal of Radon-222 from Air.......IV.3-3
  Chemical Scrubber System........................IV.3-4
  Activated Charcoal Adsorption...................IV.3-5
  Cryogenic Condensation System...................IV.3-6
  Bulkheads.......................................IV.3-7
  Summary...IV.3-8
Radon-222 Emission Controls - Uranium Milling Facilities..IV.3-9
Advanced Emission Control Systems Applicable to Uranium Mill Tailings...........................IV.3-9
  Physical Processes..............................IV.3-10
  Chemical Treatment..............................IV.3-15
Conclusions.......................................IV.3-17
References..IV.3-18

CHAPTER IV

Advanced Control Technologies

TABLE OF CONTENTS
(cont'd)

Page

Section 4: Future Control Technologies for Gaseous Radionuclide Releases....IV.4-1

Introduction....IV.4-1
Carbon-14 Control Technologies....IV.4-6
Iodine Isotopes Control Technologies....IV.4-7
  Wet Scrubbers....IV.4-7
  Solid Adsorbents....IV.4-9
  Comparison of Wet Scrubber and Solid Adsorption for Usage in Fuel Reprocessing Plants....IV.4-10
Krypton and Xenon Isotopes....IV.4-11
  Chemical Removal Methods....IV.4-11
  Physical Removal Methods....IV.4-12
  Comparison of Chemical and Physical Methods of Krypton and Xenon Removal....IV.4-15
References....IV.4-16

Section 5: Novel Particulate Control Devices....IV.5-1

Introduction....IV.5-1
Criteria for Inclusion in the Study....IV.5-2
  Respirable Particulates....IV.5-2
  Advanced Technology....IV.5-3
  Possible Application on a Wide Scale....IV.5-3
  Application to Specific Industries....IV.5-3
  Point Source Emissions....IV.5-3
Summary of Results....IV.5-3
Description of Technologies....IV.5-7
  Electrified Beds....IV.5-7
  Electrostatic Capture in Fiber Beds....IV.5-10
  Agglomeration Techniques....IV.5-14
  Magnetic Separation....IV.5-20
  Foam Scrubbing....IV.5-22
  Novel Electrostatic Precipitation Devices....IV.5-24
  Chemical Additives....IV.5-27
Comparison of Techniques....IV.5-28
  Electrified Filter Bed (EFB)....IV.5-29
  Electrostatic Capture in Fiber Beds....IV.5-32
  Agglomeration Technologies....IV.5-33
  Magnetic Separation....IV.5-35
  Foam Scrubbing....IV.5-36
  Novel Electrostatic Precipitation Devices....IV.5-37
Summary of Conclusions....IV.5-38
References....IV.5-39

CHAPTER IV

Advanced Control Technologies

LIST OF TABLES

Table		Page
2-1	Summary of Underground Filter Testing	IV.2-5
4-1	Future Control Technologies for Gaseous Radionuclide Releases	IV.4-2
4-2	Aggregated Budgets by Waste Management Area	IV.4-5
5-1	Advanced Technology Comparison	IV.5-5

CHAPTER IV

Advanced Control Technologies

LIST OF FIGURES

Figure Page

2.1 Thin Layer Leach Flow Diagram....IV.2-10

3.1 Fixation of Selected Inactive Mill Wastes in Asphalt....IV.3-11
3.2 Fixation of Mill Tailings in Cement....IV.3-13

5.1 Schematic of the Electrified Bed Technology....IV.5-9
5.2 Fiber Bed Schematic....IV.5-12
5.3 Schematic Charge Section Without Can....IV.5-13

CHAPTER IV

Appendices

TABLE OF CONTENTS

Page

Appendix IVA: Attenuation of Radon Flux and Gamma Exposure Rate from Uranium Mill Tailings....IVA-1

Analytical Approach....IVA-1
  Radon Flux Attenuation....IVA-1
  Gamma Exposure Rate Attenuation....IVA-5

Appendix IVB: Catalogue of Investigated Research on Advanced Control Technologies for Radionuclide Emissions...IVB-1

Appendix IVC: Catalogue of Investigated Research on Advanced Control Technologies for Particulate Emissions....IVC-1

CHAPTER IV

Appendices

LIST OF TABLES

Table Page

C-1 CDS Performance for Sub-Micron Particle Removal..........IVC-36
C-2 CDS vs. ESP - Performance Comparison.....................IVC-37

CHAPTER IV

Appendices

LIST OF FIGURES

Figure Page

A.1 Configuration Used to Model Radon Flux Attenuation.........IVA-2
A.2 Ratio of Surface Flux to Background Flux Versus Thickness of Cover Material...............................IVA-6

C.1 Wet Wall Electroinertial Unit..............................IVC-6
C.2 Representative Cut Diameters as a Function of Pressure Drop for Several Scrubber Types...........................IVC-54

CHAPTER V

Radiopharmaceutical Users

TABLE OF CONTENTS

Page

Introduction....................V.1-1
    Users of Radiopharmaceuticals....................V.1-1
    Isotopes of Concern....................V.1-2
Radioiodine....................V.1-7
    Sources of Airborne Radioiodine....................V.1-7
    Radioiodine Control....................V.1-8
Radioxenon....................V.1-11
    Sources of Airborne Xenon-133....................V.1-11
    Radioxenon Control....................V.1-12
    Discussion....................V.1-14
Control Costs....................V.1-16
Summary....................V.1-20
References....................V.1-21

CHAPTER V

Radiopharmaceutical Users

LIST OF TABLES

Table — Page

1-1a Frequently Performed Radiopharmaceutical Diagnostic Examinations....V.1-3
1-1b Frequently Performed Radiopharamceutical Therapy Procedures....V.1-4
1-2 Isotopes of Principle Concern....V.1-5
1-3 Radioiodine Control Technology Costs....V.1-17
1-4 Radioxenon Delivery/Control Technology Costs....V.1-18
1-5 Activated Charcoal and Ancillary Equipment Costs....V.1-19

LIST OF FIGURES

Figure — Page

1.1 Iodination Box....V.1-9

CHAPTER V

Radiopharmaceutical Users

Appendix VA

Page

Appendix VA: Abbreviated Summary of Approved Radiopharmaceutical Drug Products.................VA-1

CHAPTER I

Foreword

The information presented in the following section introduces the study, its background, scope, objectives, the organization of this report and a summary of the major findings and conclusions.

Introduction

This study is one of a series authorized by the United States Environmental Protection Agency's (U.S. EPA) Office of Radiation Programs to identify and quantify sources of airborne radioactive emissions and develop information on emission control technology.

Specifically this report presents the results of a study to assess current and future control technologies to limit airborne radioactive emissions from selected industries and facilities. The study reviewed both primary controls, i.e., technologies directly applicable to radioactive emissions, and secondary controls, i.e., those technologies primarily used to control particulate or noxious gases and in doing so control radionuclide releases. Where possible the study also identified the source and type of radioactive emission.

Background

The Clean Air Act, as amended in 1977, (section 122) directed the U.S. Environmental Protection Agency to "review all relevant information, and determine whether or not emissions of radioactive pollutants into the ambient air will cause or contribute to air pollution which may reasonably be anticipated to endanger public health".

As directed by the Act, the Office of Radiation Program's (ORP), Technology Assessment Division (TAD) was charged with the responsibility of evaluating the known and potential sources of emissions to provide a basis for the establishment, implementation and enforcement of emission limitations and standards of performance deemed necessary to protect the public health.

To accomplish this directive a program was established to:

- Identify sources and quantify the radioactive emissions from these sources.
- Develop information on air pollution control techniques.
- Assess the impact to public health.

In September of 1978, Dames & Moore was authorized by the EPA to assess information on technological systems of continuous emission reduction of airborne radioactive emissions from selected industries and facilities.

Objective

The objective of this study was to provide the Environmental Protection Agency with a data base to be used to support decisions relating to the technological feasibility and economic practicality of reduction emissions of airborne radioactive materials.

Report Organization

This report is presented in three volumes consisting of five chapters. Each chapter may be considered to "stand alone" and is basically independent of the previous or following chapters. The following is a brief synopsis of the remaining chapters.

Chapter Two reviews current control technology used to limit airborne radioactive emissions from a wide variety of industries/ facilities. These industries/facilities may be broadly classified as belonging to "the nuclear fuel cycle" (or as "other potential radionuclide emitters"). Specifically, the industries/facilities reviewed are:

- The uranium mining and milling industry
- Other nuclear fuel cycle facilities
- Other NRC-Licensed and DOE facilities
- Fossil fuel facilities
- Selected metal and non-metal extraction industries i.e., crushed stone, iron and steel, fluorspar, phosphate, bauxite, and copper.
- Other selected industries/facilities, i.e., geothermally produced electricity, and selected ground water users.

Also included in this chapter are five appendices. These discuss HEPA filter costs, generic descriptions of electrostatic precipitators, fabric filter devices and scrubbers, and a review of a geothermal facility's radionuclide monitoring program.

Chapter Three considers the existing airborne emission control technologies in terms of specific radioactive isotopes that can be found in airborne effluents. The discussion of this chapter is limited to the airborne emission control technologies utilized at "nuclear" facilities, i.e., facilities that handle material containing radioactivity, release radionuclides in their airborne effluents, and are required to meet radiological airborne emission regulations and/or criteria.

Chapter Four reviews advanced control technologies which may be used to reduce radioactive particulate and gaseous emissions. The review includes both devices and, where applicable, process improvements. The format of this chapter is similar to that of Chapter Two. Research and development for potential use by the uranium mining and milling industry is reviewed first. This is followed by a review of advanced systems for the remainder of the nuclear fuel cycle. The final section deals with novel particulate control research. The novel devices are primarily those useful in controlling the respirable fraction of particulate emissions. Appendices to the chapter include a catalog of the research investigated.

Chapter Five reviews users of radiopharmaceuticals, both diagnostic and theraputic, and any control measures which may be used to limit their atmospheric emissions. Also included is an abbreviated summary of approved radiopharmaceutical drug products.

General Methodology

The wide variation in facilities required that a general methodology be established to assess the various airborne control technologies. The methodology chosen consisted of a two-step process. The initial screening used the following general guidelines.

- The control technology must have been in commercial use in the industry considered.

- The control technology must have widespread applicability, and not be unique to a particular facility which may have a special problem.

- In general, the most recently constructed facilities had the most current technologies.

- The control technology must enable the facility to satisfy air quality standards for particulates where applicable. This is especially true for those facilities where radiological data did not exist.

These guidelines were generally applied to all industries considered for the project, and when possible used to identify candidate technologies for further evaluation.

Two major categories of technologies resulted from the initial screening.

- Primary controls, i.e., those with the sole purpose of removing radionuclides,

- Secondary controls, i.e., those with the purpose of removing particulates, and implicity removing radioactive particulates.

The criteria used for evaluation by category are as follows:

Category 1 - Primary Controls

a. Efficiency = $\frac{\text{pCi prevented from being released}}{\text{pCi input to control device}}$

b. Costs - Costs should encompass capital costs of the device and annual operating costs. Where applicable, a range of costs are given.

c. Energy Use - The average annual energy consumption by the control system in question.

Category 2 - Secondary Controls

a. Efficiency = $\frac{\text{mass prevented from being released}}{\text{mass input to control}}$

b. Costs - Costs encompassed capital costs of the device and annual operating costs. Where applicable, a range of costs are given.

c. Energy Use - The average annual energy consumption by the device in question.

d. Residuals - Where possible the residuals were defined.

These criteria were used to the extent practicable considering available data. Efficiency was the primary determinant in selecting technologies. This methodology is considered to be general enough to all the industries/facilities reviewed.

Where the methodology could not be applied, an overview of the control technologies is presented.

Data Acquisition

The data used in this study were predominately obtained from the open literature, prior and current studies by various state and local agencies, previous Dames & Moore studies, various industry representatives, and commerical and non-commercial computerized data bases. Table 1-1 presents a partial list of sources of data.

The data acquisition methodology varied somewhat between the two major industry/facility classifications (nuclear and non-nuclear). Appendix I.A reviews in greater detail the scope of the data sources.

Conclusions

Due to the voluminous nature of the report, only the major overall conclusions are listed herein. These are:

TABLE I-1

Sources of Data

Academia

- Colorado State University
- Columbia University
- Iowa State University
- Michigan State University
- North Carolina State University
- Pennsylvania State University
- Princeton University
- Rutgers University
- Texas A & M
- University of California
- University of Delaware
- University of Duluth
- University of Florida
- University of Minnesota

Associations

- American Hygienist Association
- American Institute of Mining
- Metallurgical & Petroleum
- Engineers - Society of Mining Engineers
- American Mining Congress
- American Petroleum Institute
- American Water Works Association
- Electric Power Research Institute
- National Coal Association
- National Council on Radiation Protection & Measurements
- National Petroleum Association
- Natural Gas Association
- Pharmaceutical Association of NY
- Pharmaceutical Food & Drug Administration
- Pharmaceutical Manufacturing Association
- Society of Nuclear Medicine
- Water Facts Consortium
- Water Quality Association

Commercial Sector

- Commercial/Computerized Data Bases
- Industrial Gas Cleaning Institute
- The McIlvaine Co.
- Midwest Research Institute
- Reports From Consulting Organizations
- Southern Research Institute

Federal Agencies

- Bureau of the Census (D.O.C.)
- Bureau of Mines (D.O.I.)
- Department of the Army
- Department of Energy
- Department of the Interior
- Environmental Protection Agency
- Federal Energy Regulatory Commission (D.O.E.)

Industrial Sector

- Coal
- Natural Gas
- Petroleum
- Uranium Mining and Milling
- Utilities

International Agencies

- International Atomic Energy Agency (I.A.E.A.)
- International Council on Radiation Protection (I.C.R.P.)

TABLE 1-1 (cont'd)

Sources of Data

Federal Agencies

Food & Drug Administration (D.H.E.W.)
Geological Survey (D.O.I.)
Library of Congress
Mine Safety and Health Administration (D.O.L.)
National Institutes of Health (D.H.E.W.)
National Technical Information Service (D.O.C.)
Nuclear Regulatory Commission
Oak Ridge National Laboratories (D.O.E.)
Patent & Trademark Office (D.O.C.)
Public Health Service (D.H.E.W.)

State Agencies

Agreement States (25)
Various State
  Radiological/Environmental
  Health Programs

- Data regarding radiological emissions in all but the nuclear industry is sparse and varied.

- Data regarding non-radioactive particulate emissions is also sparse and varied especially for particulates in the "respirable" range.

- No standard methodology exists for many industries in selecting the control devices to be used at source points.

- The majority of control devices quote mass efficiencies. As most of the radioactivity is associated with particulates in the respirable range these quoted efficiencies may not be applicable.

- A potential exists for elevated radon/radionuclide releases from a variety of industries/facilities not previously associated with radioactivity.

Specific conclusions or recommendations for a particular industry/facility may be found in the text.

Despite the mass of data collected, significant "gaps" exist which warrant recommending further studies. It is hoped that this report however may point out these "gaps" and may help in establishing the data base necessary to fulfill the overall objectives of the Clean Air Act.

CHAPTER II

Section 1: Introduction

Background

This chapter reviews current control technology used to limit airborne radioactive emissions from a wide variety of industrial facilities. The industries/facilities can be broadly classed as belonging to "the nuclear fuel cycle" (Sections 2 and 3) or "other potential radionuclide emitters" (Section 4, 5, 6, and 7). Specifically the sections are:

- The uranium mining and milling industry
- Other nuclear fuel cycle facilities
- Other NRC-Licensed and DOE facilities
- Fossil fuel facilities
- Selected metal and non-metal extraction industries
- Selected non-nuclear facilities (geothermal power facilities and ground water users)

A brief synopsis of each section is presented in Table 1-1.

Also included in this chapter are three appendices. These include a discussion of HEPA filter costs, generic descriptions of electrostatic precipitators, fabric filter devices and scrubbers and a review of a geothermal facility's radionuclide monitoring plan.

TABLE 1-1

Review of Individual Sections

Section Number	Title	Summary
2	The Uranium Mining and Milling Industry	This section reviews the industry and the processes associated with the production of yellowcake. The results of a literature search and discussions with various mill operators regarding the emission of radon and particulates and associated controls are presented.
3	Other Nuclear Fuel Cycle Facilities	This section considers current airborne emissions control technologies in commercial nuclear fuel cycle facilities. These include uranium conversion plants, enrichment facilities, fuel fabrication plants, central station nuclear power plants, fuel reprocessing and waste management facilities.
4	Other NRC-Licensed and DOE Facilities	The facilities of concern in this section are: reactors other than central station; facilities with "special nuclear material", "source material" or "by product material" licenses not previously considered; high energy accelerators; fusion energy facilities; weapon systems associated facilities; and several national laboratories.
5	Fossil Fuel Facilities	This section begins with a brief review of particulate emission from the storage, transport and mining of coal. The radioactivity of coal is also reviewed. Three particulate control devices are generically discussed along with their use in electric generating plants.
6	Selected Metal and Non-Metal Extraction Industries	This section reviews the possible contribution of radioactive airborne emissions from the stone, iron, phosphate, bauxite, fluorspar and copper industries. The format followed for each industry includes: industry description, ore geology and radionuclide content, process description, airborne radionuclide or particulate emissions and airborne radionuclide or particulate emission controls.
7	Selected Non-nuclear Facilities	The selected non-nuclear facilities reviewed were those producing electricity from geothermal energy sources and ground water treatment plants.

Outline

Every section of this chapter is essentially a "stand alone" section. Thus references for each section immediately follow.

The generalized format established for each section of the chapter is as follows:

Each industries/facilities process or operation is reviewed. Where possible, data is presented regarding the amount of airborne radioactivity released by the operations. When this type of data is not available, airborne particulate releases are considered. Finally, airborne radionuclide or particulate emission controls are discussed.

The available information presented on the control includes control type, effectiveness, capital and operating expenses, and residuals generated. The information ranges from extensive to meager depending upon the process and industry.

CHAPTER II

Section 2: The Uranium Mining and Milling Industry

Background

The mining and milling of uranium used in nuclear power plants initiates the nuclear fuel cycle. Although part of the cycle, sufficient differences exist which warrants reviewing this industry separately from the remainder of the cycle. These differences include the type of operations involved, and forms of final waste. This section will therefore review the industry, identify the possible sources of airborne radiological emissions and review the current control technology employed therein. Other sections of this chapter will survey the remainder of the fuel cycle. Lastly, as the devices employed in the industry are basically particulate control devices, no generic description will be discussed in this section. Generic device descriptions may be found in section 5, "Fossil Fuel Facilities".

Data Acquisition

The following sources of information were used to establish the data base for this section of the report:

o Direct contact with either the Radiation Safety Officer, the Mill Superintendent or the Mine Superintendent at several uranium facilities.

o Review of Environmental Impact Statments and Environmental Reports.

o Review of documents available in the NRC Document Room, Washington D.C.

- o Contact with industrial associations such as the Atomic Industrial Forum, the American Mining and Milling Congress, and Industrial Gas Cleaning Institute.

- o Review of the EPA's National Emission Data (NED) System to determine if data was available on the emissions from uranium mills.

- o Direct contact with Bureau of Mines personnel.

The most productive of these sources of information on the types of control technology currently used were the mine/mill operators, personnel from the U.S. Bureau of Mines, and the data available in the NRC's public document room. Inquires to the NED system and to the Industrial Gas Cleaning Conference provided minimal data as the uranium industry does not have a Standard Industrial Classification number and is not contained within either of these data systems.

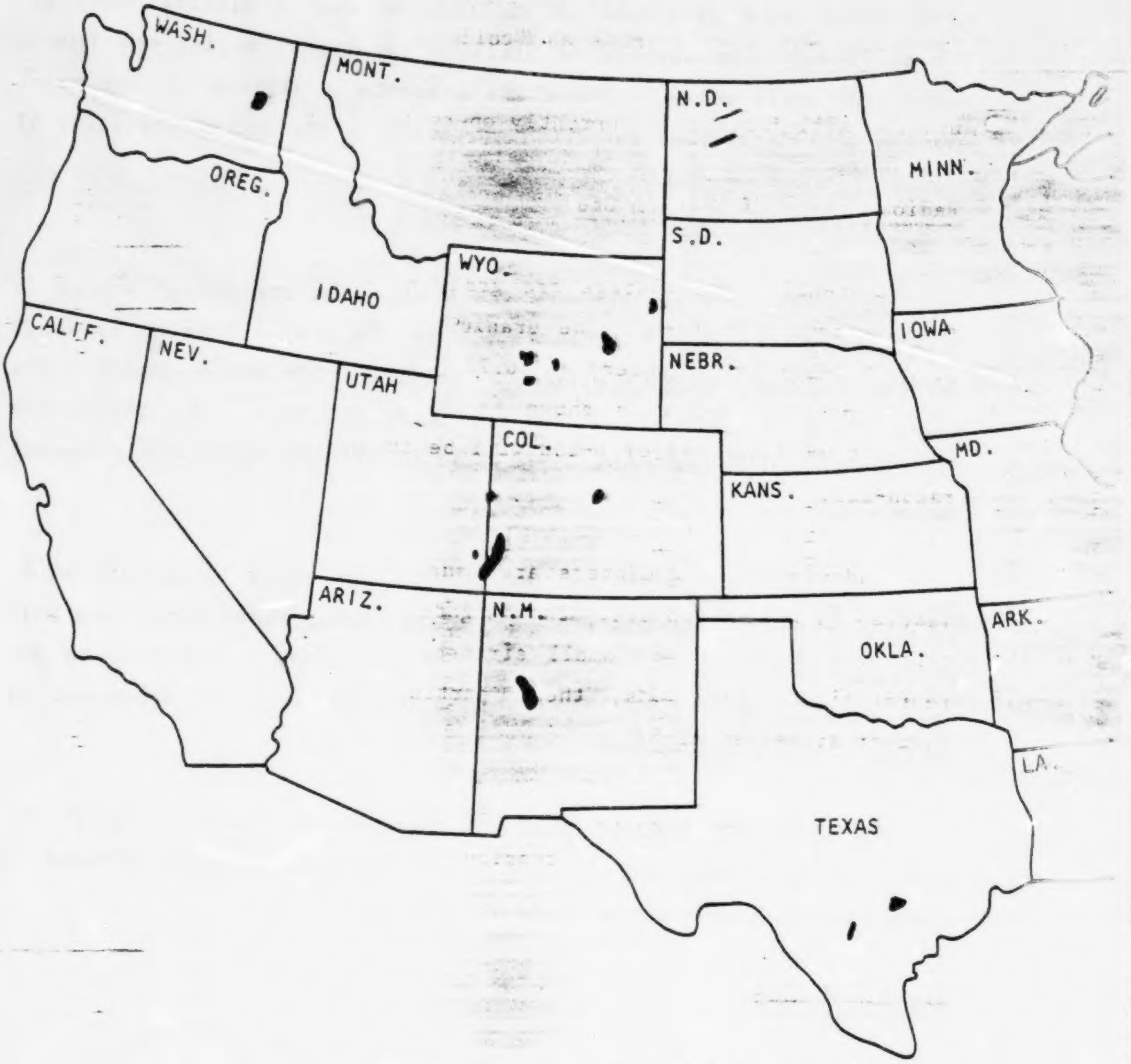
Industry Profile

In the United States, the uranium mining and milling industry is confined, primarily, to the states of New Mexico, Wyoming, Utah, and Colorado with smaller operations located in Texas and Washington. In 1977, approximately 15,310 short tons of yellowcake* were produced by the industry with New Mexico and Wyoming accounting for 49 percent and 33 percent of the total product (2-1, 2-2). The location of the major uranium mining and milling districts is shown in Figure 2.1. (2-3)

For perspective, in 1960, there were approximately 965 uranium mines in operation in the western states. By the mid seventies, the numbers of producing operations had decreased to 173, with 12 of the

---

*The final product of the mill although referred to as yellowcake is primarily uranium oxide (U_3O_8), other oxides and sodium and ammonium uranates.


WASH.
MONT.
N.D.
MINN.
OREG.
IDAHO
S.D.
WYO.
IOWA
CALIF.
NEV.
NEBR.
UTAH
COL.
MO.
KANS.
ARIZ.
N.M.
ARK.
OKLA.
LA.
TEXAS

PRINCIPAL URANIUM DEPOSITS OF THE UNITED STATES

Source: Reference 2-4

DAMES & MOORE

FIGURE 2-1

mines producing 95% of the total annual ore output.(2-1) Most of the major mines were developed in conjunction with a milling facility. The mills may also operate as "tolling" stations, buying ore from a number of small mines. Table 2-1 presents a listing of the major uranium mill facilities currently operating in the United States.(2-4)

Radioactivity of Uranium Ore

Currently, the average ore grade mined in the United States is 0.16 percent U_3O_8.(2-4) The uranium in the ore is present as 99.28 percent U-238 and daughters and 0.71 percent U-235 and daughters. The decay chain of U-238 is shown in Figure 2.2.(2-4) Typically, the radioactive daughters of U-238 will be in secular equilibrium through radon-222.

Radon and its daughters are usually not found in secular equilibrium in the atmosphere. The daughters, being heavy metal ions will typically plate out on small airborne particles. Depending on meteorological conditions, these particulates will be deposited or further dispersed.(2-5).

The principal radionuclides of concern are found in Table 2-2. (2-6) A more detailed discussion of the environmental effects of these radionuclides may be found in Reference 2-4.

Uranium Mining

Mining Methodologies

Currently, commercial uranium mining operations can be classified as underground (shaft) mines, surface (open-pit) mines or in-situ leaching operation.

Underground uranium mines range from simple adits into a canyon

TABLE 2-1

U.S. Uranium Ore Processing Mills Operating in 1978[a]

State & Company	Location	Max Cap. MT ore/day	Process Used
New Mexico			
Anaconda Company	Grants	2,720	Acid leach, CCD, solvent extraction
Kerr-McGee Nuclear Corporation	Grants	6,360	Acid leach, CCD, solvent extraction
Sohio-Reserve	Cebolleta	1,500	Acid leach, CCD, solvent extraction
United Nuclear Corporation	Church Rock	2,720	Acid leach, CCD, solvent extraction
United Nuclear-Homestake Partners	Grants	3,170	Carbonate leach, caustic precipitation
Wyoming			
Exxon, U.S.A.	Powder River Basin	2,720	Acid leach, CCD, solvent extraction
Federal-American Partners	Gas Hills	860	Acid leach, eluex
Lucky Mc Uranium Corporation	Gas Hills	1,500	Acid leach, eluex
Lucky Mc Uranium Corporation	Shirley Basin	1,630	Acid leach, CCD, column ion exchange
Petrotomics	Shirley Basin	1,600	Acid leach, CCD, solvent extraction
Rocky Mtn. Energy & Mono Power	Powder River Basin	910	Acid leach, CCD, solvent extraction
Union Carbide Corporation	Natrona County	1,090	Acid leach, eluex
Western Nuclear, Inc.	Jeffrey City	1,540	Acid leach, eluex
Utah			
Atlas Corporation	Moab	1,000	Carbonate leach, resin in pulp & acid leach, solvent extraction
Rio Algom Corporation	La Sal	640	Carbonate leach, caustic precipitation
Colorado			
Cotter Corporation	Canon City	400	Carbonate leach, caustic precipitation
Union Carbide Corporation	Uravan	1,170	Acid leach, CCD, column ion exchange
Texas[b]			
Chevron	Pana Maria	2,250	Acid leach, CCD, solvent extraction
Conoco & Pioneer Nuclear, Inc.	Falls City	2,500	Acid leach, CCD, solvent extraction
Intercontinental Energy Corp.	Pawnee	—	In situ leaching, column ion exchange
Mobil Oil Company	Bruni	—	In situ leaching, column ion exchange
U.S. Steel	George West	—	In situ leaching, column ion exchange
U.S. Steel-Niagara Mohawk	George West	—	In situ leaching, column ion exchange
Wyoming Mineral Corporation	Bruni & Ray Point	—	In situ leaching, column ion exchange

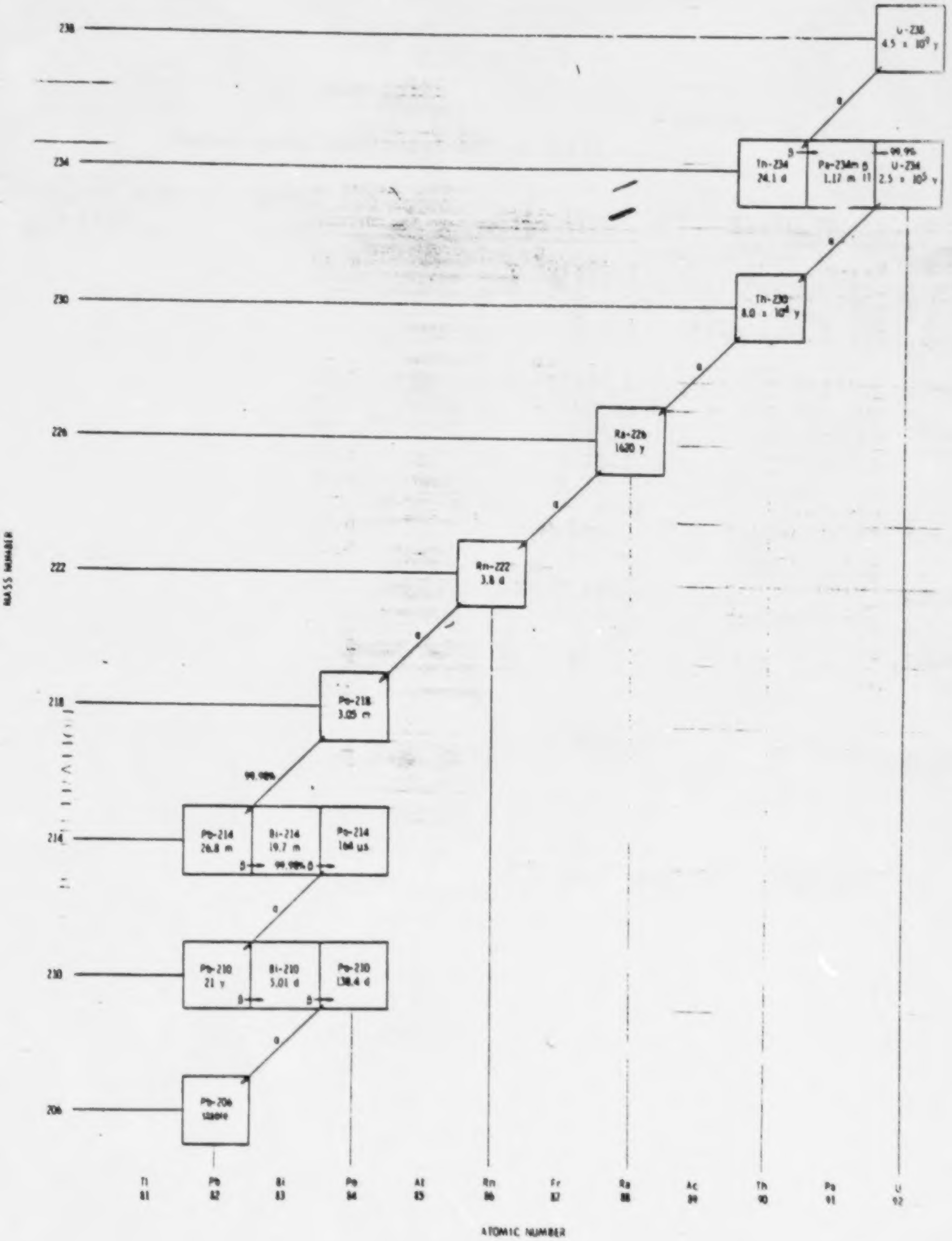
TABLE 2-1 (cont'd)

U.S. Uranium Ore Processing Mills Operating in 1978[a]

State & Company	Location	Max Cap. MT ore/day	Process Used
Washington			
Dawn Mining Corporation	Ford	400	Acid leach, CCD, column ion exchange
Western Nuclear	Wellpinit	1,800	Acid leach, CCD, solvent extraction
TOTAL		38,470	

---

a. Does not include a Forida site that is extracting uranium from phosphoric acid.
b. Modified from J.F. Facer, Jr., "Uranium Production Trends," presented at the Grand Junction Office Uranium Industry Seminar, U.S. Dept. of Energy, October, 1977, from Reference 2-4.


MASS NUMBER
238
234
230
226
222
218
214
210
206
U-238
4.5 x 10⁹ y
α
Th-234
24.1 d
β
Pa-234m
1.17 m
β
99.9%
U-234
2.5 x 10⁵ y
α
Th-230
8.0 x 10⁴ y
α
Ra-226
1620 y
α
Rn-222
3.8 d
α
Po-218
3.05 m
99.98%
Pb-214
26.8 m
Bi-214
19.7 m
Po-214
164 us
β
99.98% β
α
Pb-210
21 y
Bi-210
5.01 d
Po-210
138.4 d
β
β
α
Pb-206
stable
Tl 81
Pb 82
Bi 83
Po 84
At 85
Rn 86
Fr 87
Ra 88
Ac 89
Th 90
Pa 91
U 92
ATOMIC NUMBER

THE URANIUM-238 DECAY SERIES.

Source: Reference 2-4

DAMES & MOORE

TABLE 2-2*

Uranium-238 Principal Decay Modes

Radionuclide	Half-Life	Alpha Energy (MeV)	Beta Energy (MeV)	Gamma Energy* (MeV)
Uranium-238	4.51×10^9 y	4.20		
Thorium-234	24.1 d	—	0.19	0.09
Protactinium-234	6.7 h	—	1.32 1.13	1.00
Uranium-234	2.47×10^5 y	4.77		0.05
Thorium-230	80,000 y	4.68		0.07
Radium-226	1,620 y	4.78		0.19
Radon-222	3.82 d	5.49		0.51
Polonium-218	3.05 m	6.00		—
Lead-214	26.8 m	—	1.03	0.35
Astatine-218	1.5-2.0s	6.63	—	—
Bismuth-214	19.7 m	5.45	3.26	0.61
Polonium-214	1.6×10^{-4} s	7.69	—	0.80
Thallium-210	1.32 m	—	1.9	0.80
Lead-210	22 y	3.72	0.06	0.05
Bismuth-210	5.0 d	4.65	1.16	—
Polonium-210	138 d	5.31	—	0.80
Thallium-206	4.2 m	—	1.15	—
Lead-206	Stable	—	—	—

---

* Adapted from Reference 2-6.

wall to large underground excavations. The larger uranium ore bodies for example may lie several hundred to a thousand feet underground, be one-half mile long, several hundred feet wide and five to one hundred feet thick.(2-7) They also tend to be long, thin and erratic in occurrence.

Mining methods may vary but usually include some combination of room and pillar, sub-level open stoping or cut and fill stoping.(2-8)

Basically, the ore body is drilled, blasted and the ore transported by a scrape loader (slusher) to a shaft (ore pass) which connects with the hoisting shaft.(2-4) There, hoisting skips transport the ore to the surface to be transported to the mill.

Open pit mining is conducted when the ore body is relatively shallow and overburden consists of loosely consolidated soil.(2-4) In most instances the ore deposits mined by this method are no deeper than 300 feet although some deposits have been surfaced mined to depths greater than 500 feet. Unlike underground mining, in many instances drilling and blasting are not necessary. Usually stripping equipment such as tractors with rippers, scrapers or a diesel power shovels is sufficient.(2-4)

In-situ leaching represents a fairly recent technology which has been used with increased frequency throughout the industry.(2-9) In 1977, in-situ leaching accounted for 2.3% of the total annual yellowcake production of 15,310 short tons.(2-2) Typically, a suitable leach solution (lixiviant) is injected into the ore zone. The lixiviant percolates through the ore body, mobilizing (dissolving) the uranium. The final pregnant (uranium bearing) solution is then pumped to the surface via recovery wells for further processing. A more complete discussion of this method may be found in References 2-4 and 2-9.

Current Control Technology in Uranium Mining

Underground Mines

Discussions with mine personnel indicate that no emission control technologies are currently applied directly to the exhausts from underground mines in order to limit radioactive particulate or gas discharge.

In the mine, however, present standards restrict the concentrations of radon daughters to less than 1.0 working level (WL).(2-10)

A working level is defined as any combination of radon daughters in 1 liter of air that will result in the ultimate emission of $1.3x10^5$ million electron volts (Mev) of alpha energy in decaying through polonium-214. Under equilibrium conditions, one WL is approximately equal to a radon-222 concentrations of 100 pCi/liter. For the areas where exposure to concentrations of radon daughters exceeds 0.3 WL complete individual exposure records must be kept.

Lastly, no employee may receive an exposure in excess of 4 working level months (WLM) in any calendar year where one WLM is defined as "exposure to a concentration of 1 WL for 173 hours".(2-10)*

In order to maintain mine personnel exposures to radon and radon daughters at less than the maximum permissible levels, operating underground mines currently use mechanical ventilation as the primary means of diluting and removing the radioactive particulates and gases from the work areas. Also, worked out areas are routinely sealed-off by use of bulkheads, backfilling or collapse (room and pillar mining techniques). These techniques are used to improve ventilation efficiency, provide mine stability and control contaminant influx from the worked out area.(2-8) The effects of these and other techniques such as air filtration, overpressurization and sealants on the total activity release from active underground uranium mines are unknown at this time.

---

* Subsequent to the time of this writing, The Mine Safety and Health Administration of the Department of Labor published new standards for radon/radon daughter exposure protection. These standards are published in the Federal Register, Vol. 44 No. 107, June 1979 and concern 30 CFR Parts 55, 56, and 57.

Currently, both the EPA and the Bureau of Mines are engaged in research to control radon emission in undergound mines and subsequent emission to the environment. A more detailed discussion of the experimentally demonstrated radon-222 control technologies used to control working levels in uranium mines is presented in Chapter Four.

Open Pit Uranium Mines

Conversations with mine and mill superintendents at selected operating open-pit uranium mines revealed that dust emissions from the pit are routinely controlled by use of a water sprinkling system on an as needed basis. Sprinkling is carried out to reduce fugitive dust emissions to below applicable guideline levels. The need to apply this system to an exposed ore body is dependent on the moisture content of the ore. It is commonly acknowledged that ores with a moisture content of approximately 10% or greater do not require any form of emission control.

The effect of the water sprinkling technique on reducing radioactive particulate emissions from the total pit area (working and non-working sections) is unknown. The effect on radon-222 emission is also unknown, but is generally accepted to be negligible.

In-Situ Solution Mining

Dust emissions associated with in-situ leaching operations are confined primarily to the plant construction and well emplacement stages. Removal of the uraniuum from the host rock involves the use of a lixiviant solution to leach the uranium. The wells used in the injection and recovery stages of the lixiviant chemistry circuit are cased and the well heads are capped and fitted with a valve for pregnant solution removal. As a result there are no radioactive particulate or radon-222 airborne emissions associated with the mining operation itself over and above that associated with the natural existence of the uranium ore body. However, conversations with knowledgable individuals in industry and government indicate that significant Radon-222 emission may be associated with the primary hold-up tanks.

Uranium Milling

Uranium Ore Processing

In the conventional cases, the ore produced from a shaft or surface mine is transported by truck or rail car to the milling facility. There it is stored, sorted and upgraded prior to mill processing. The sorting and upgrading helps provide ore having roughly the same physical and radiological characteristics which aids in achieving an optimum process flow.(2-7)

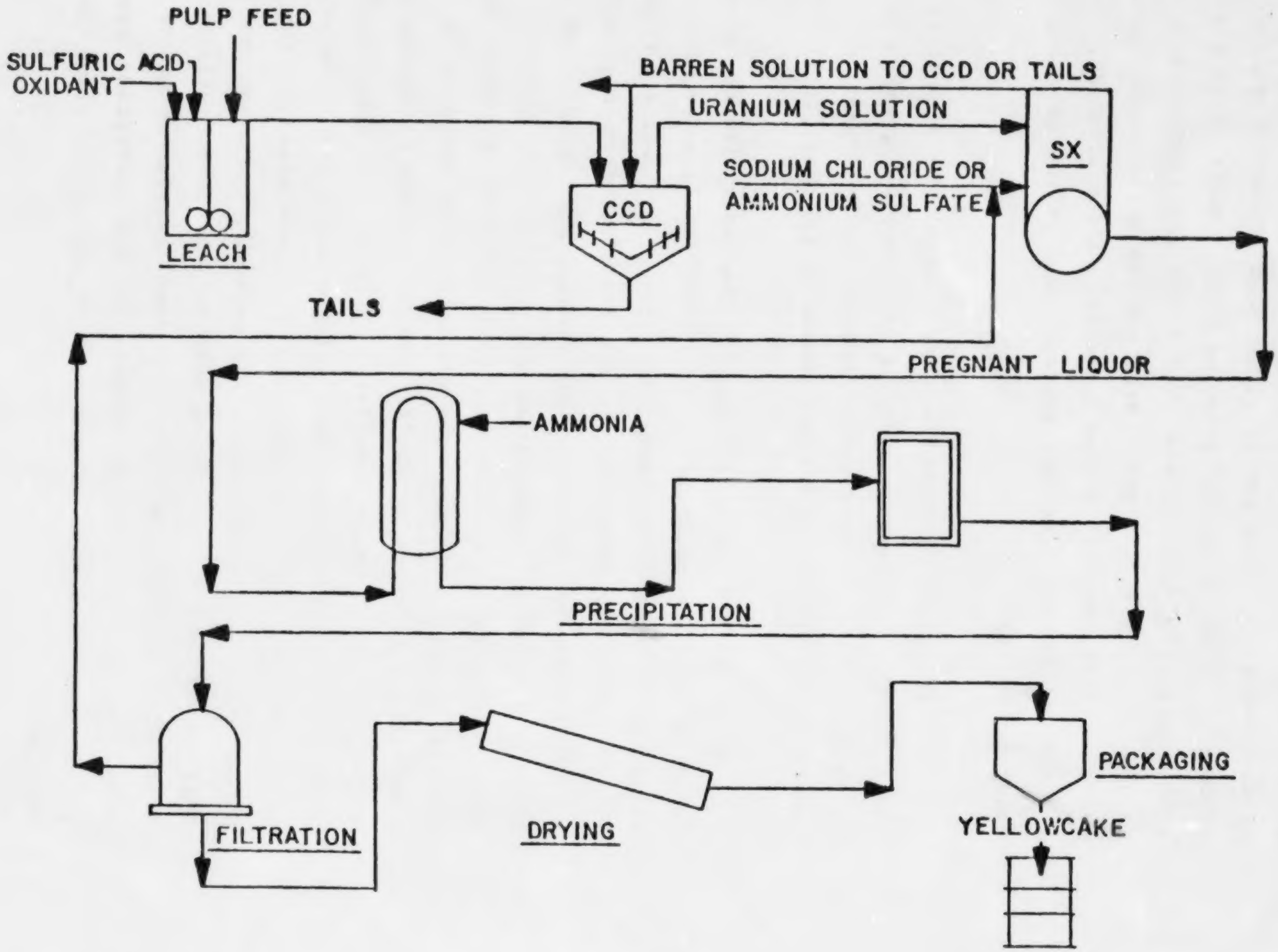
The leaching process used for mined ore is dependent on the calcium oxide (lime) content of the host rock. High lime content ores (CaO content greater than 12 percent by weight) are processed by an alkaline leach circuit that uses a sodium carbonate/bicarbonate solution. Ores with low lime content (less than 12 percent CaO) are leached using an acid solution, most commonly sulfuric acid.(2-11)

The stored ore is loaded into the mill's receiving bins by use of front end-loaders or bulldozers. Depending on the type of leach process used (acid or alkaline) and the grinding mill type (ball, rod, or semi-autogenous) the ore is either sent through a primary crushing circuit or directly to the grinding mill. Mills using a semi-autogenous grinding circuit and acid leach process do not, usually, require crushing of the ore. Ball and rod mills require crushing of ore to a size range of 0.25-1.0 inches. After crushing, the ore is transferred to the fine ore storage bins before grinding and subsequent leaching.

The major physical difference between the processes at this stage is that acid leach processing mills require grinding of the ore to approximately 25 mesh while alkaline leach process mills require upwards of 80 percent of the ore ground to 200 mesh.(2-11)

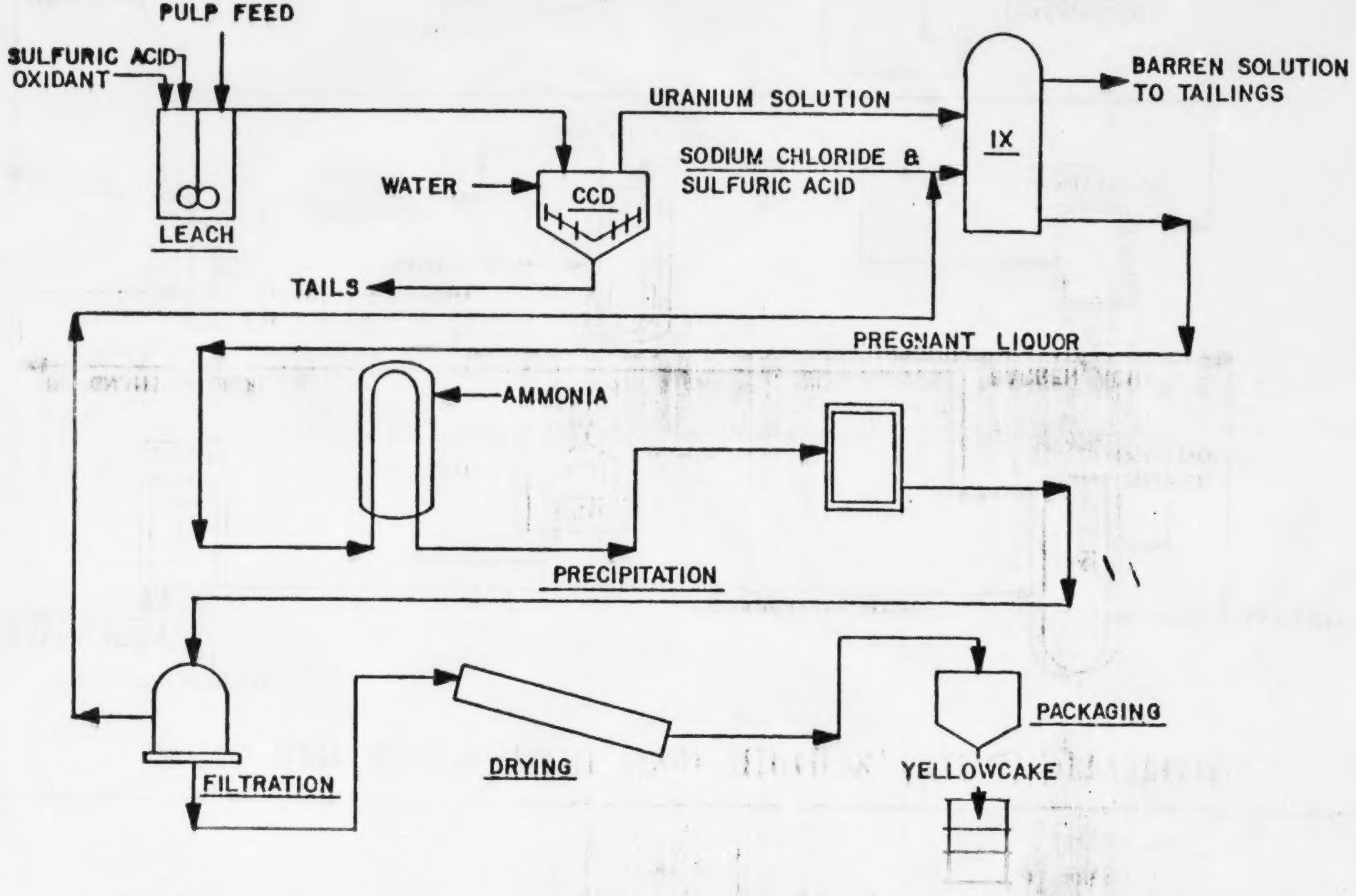
After the ore has passed through the leach circuit, the pregnant (uranium bearing) solution is separated from the solids by use of liquid-solid separation techniques, primarily countercurrent decantation. The now barren solids are transferred to the tailings impoundment area for disposal. The uranium bearing solution is passed through a uranium concentration and purification system. The concentrated uranium is then precipitated from solution by use of gaseous ammonia. Lastly, the precipitate is dried in a hearth at temperatures in excess of 700°F. Typical process flowsheets are shown in Figures 2.3 through 2.9.(2-12) Figure 2.10 presents the major potential points of particulate release which are: the ore storage area, the crushing operation and fine ore storage, the grinding circuit, the drying oepration, the packaging operation and the tailings impoundment area. These will be subsequently discussed. The dried final product (yellowcake) is then transferred to the packaging area for packaging in Department of Transportation approved 55 gallon steel drums for shipment to a UF_6 conversion plant (Chapter Two, Section 3).

ACID LEACH SOLVENT EXTRACTION (SX)


PULP FEED
SULFURIC ACID
OXIDANT
LEACH
CCD
TAILS
BARREN SOLUTION TO CCD OR TAILS
URANIUM SOLUTION
SODIUM CHLORIDE OR
AMMONIUM SULFATE
SX
PREGNANT LIQUOR
AMMONIA
PRECIPITATION
FILTRATION
DRYING
PACKAGING
YELLOWCAKE

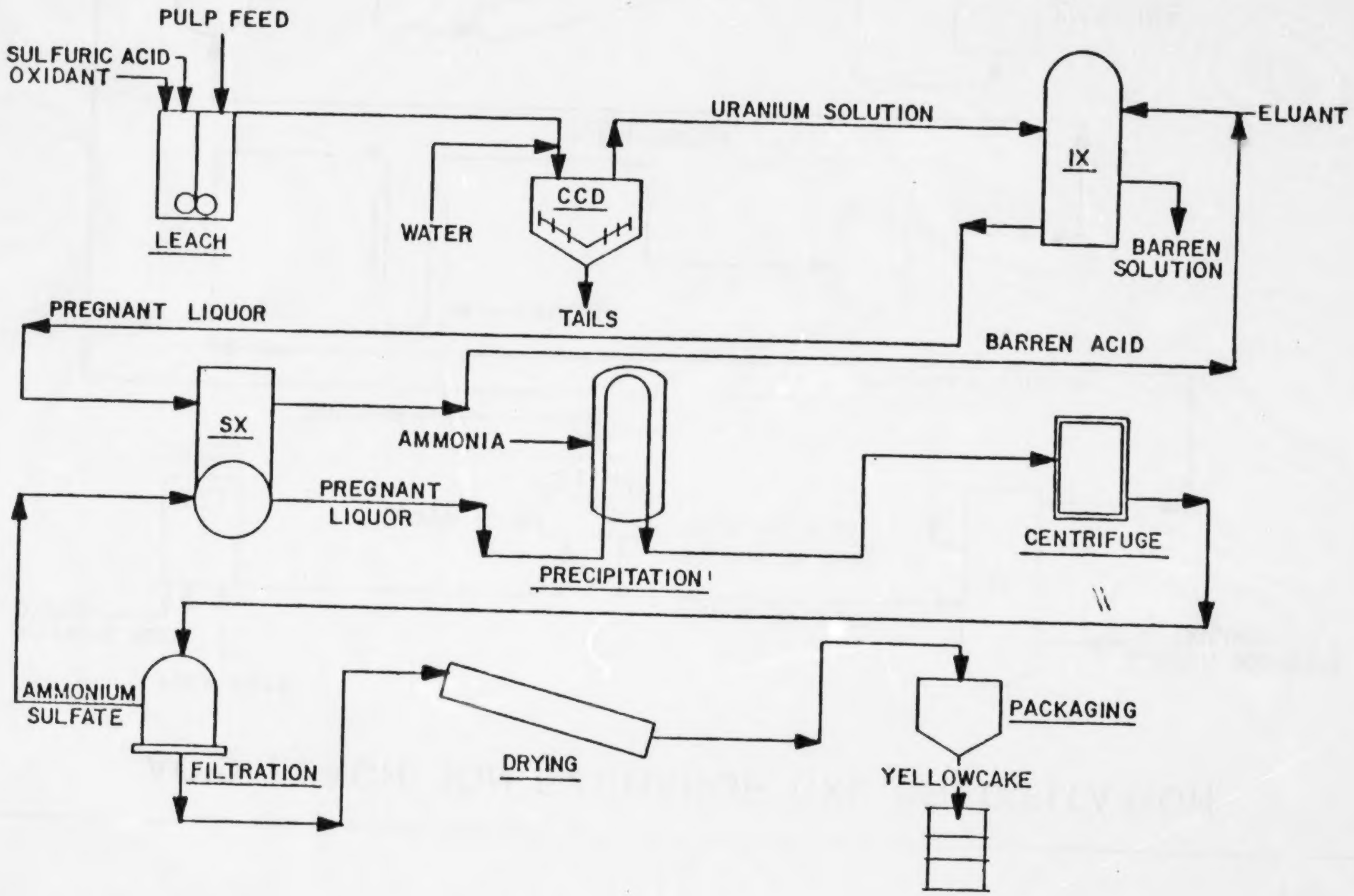
Source: Reference 2-7

ACID LEACH, ION EXCHANGE (IX), PRECIPITATION


PULP FEED
SULFURIC ACID
OXIDANT
LEACH
WATER
CCD
TAILS
URANIUM SOLUTION
SODIUM CHLORIDE &
SULFURIC ACID
IX
BARREN SOLUTION
TO TAILINGS
PREGNANT LIQUOR
AMMONIA
PRECIPITATION
FILTRATION
DRYING
PACKAGING
YELLOWCAKE

Source: Reference 2-7

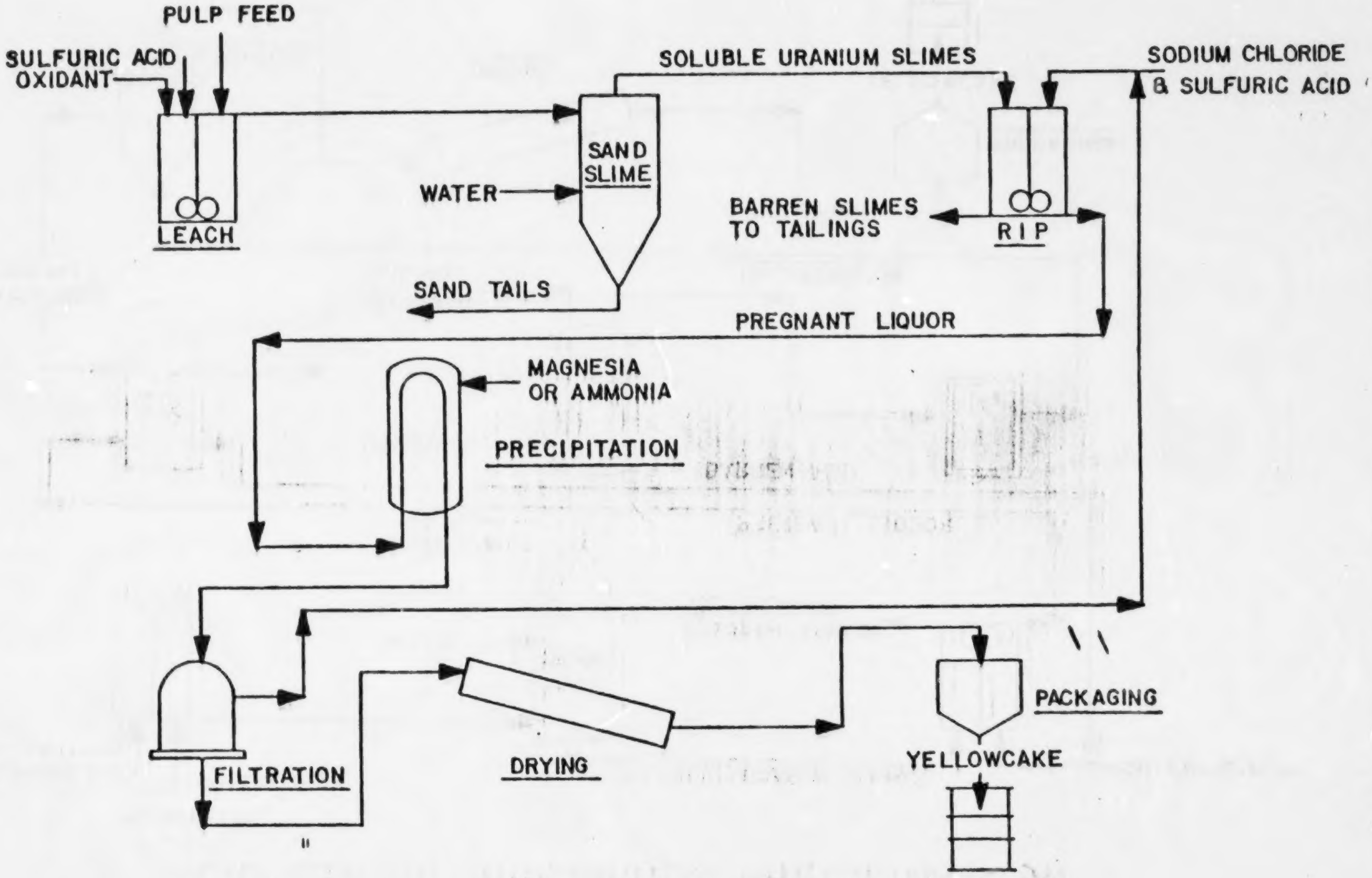
ACID ION EXCHANGE (IX), ELUEX, PRECIPITATION


PULP FEED
SULFURIC ACID
OXIDANT
LEACH
WATER
CCD
TAILS
URANIUM SOLUTION
IX
ELUANT
BARREN SOLUTION
PREGNANT LIQUOR
BARREN ACID
SX
AMMONIA
PREGNANT LIQUOR
PRECIPITATION
CENTRIFUGE
AMMONIUM SULFATE
FILTRATION
DRYING
PACKAGING
YELLOWCAKE

Source: Reference 2-7

FIGURE 2.5

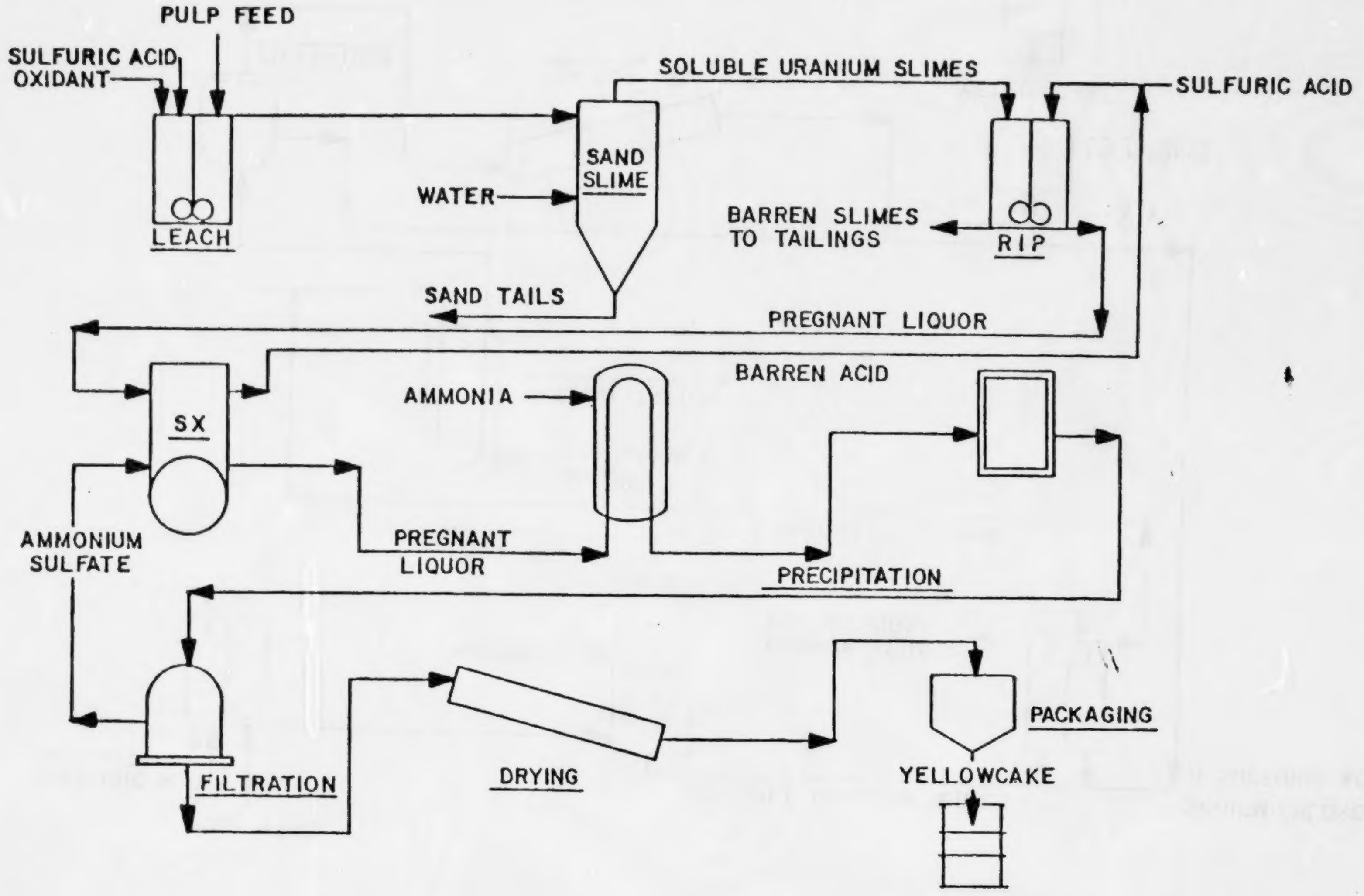
ACID LEACH, RIP, PRECIPITATION


PULP FEED
SULFURIC ACID
OXIDANT
LEACH
WATER
SAND
SLIME
SAND TAILS
SOLUBLE URANIUM SLIMES
SODIUM CHLORIDE
& SULFURIC ACID
BARREN SLIMES
TO TAILINGS
RIP
PREGNANT LIQUOR
MAGNESIA
OR AMMONIA
PRECIPITATION
FILTRATION
DRYING
PACKAGING
YELLOWCAKE

Source: Reference 2-7

FIGURE 2.6

ACID LEACH, RIP, ELUEX, PRECIPITATION

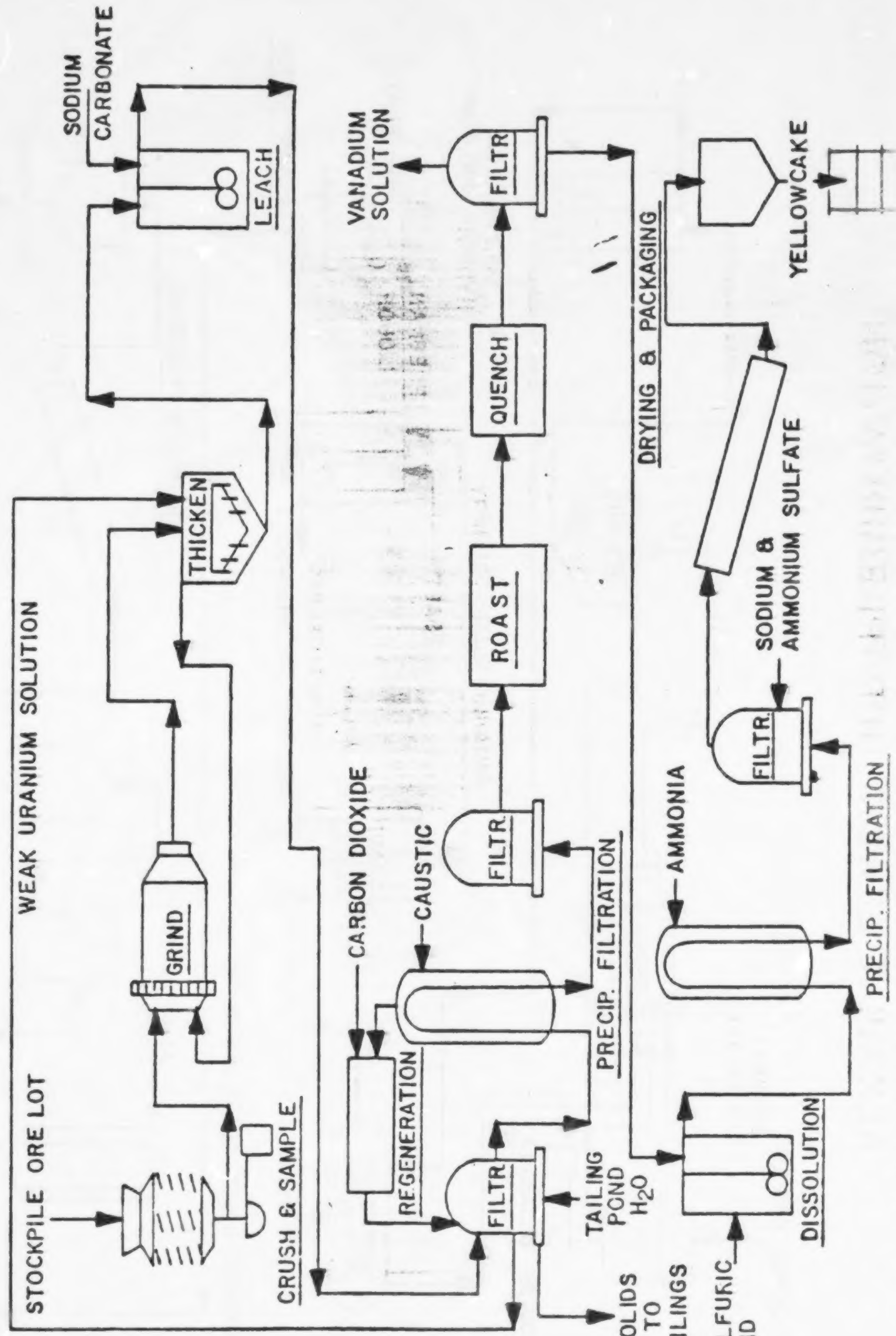

PULP FEED
SULFURIC ACID
OXIDANT
LEACH
WATER
SAND
SLIME
SAND TAILS
SOLUBLE URANIUM SLIMES
SULFURIC ACID
BARREN SLIMES
TO TAILINGS
RIP
PREGNANT LIQUOR
BARREN ACID
SX
AMMONIA
PREGNANT
LIQUOR
PRECIPITATION
AMMONIUM
SULFATE
FILTRATION
DRYING
PACKAGING
YELLOWCAKE

Source: Reference 2-7

DAMES & MOORE

FIGURE 2.7

ALKALINE LEACH, CAUSTIC PRECIPITATION

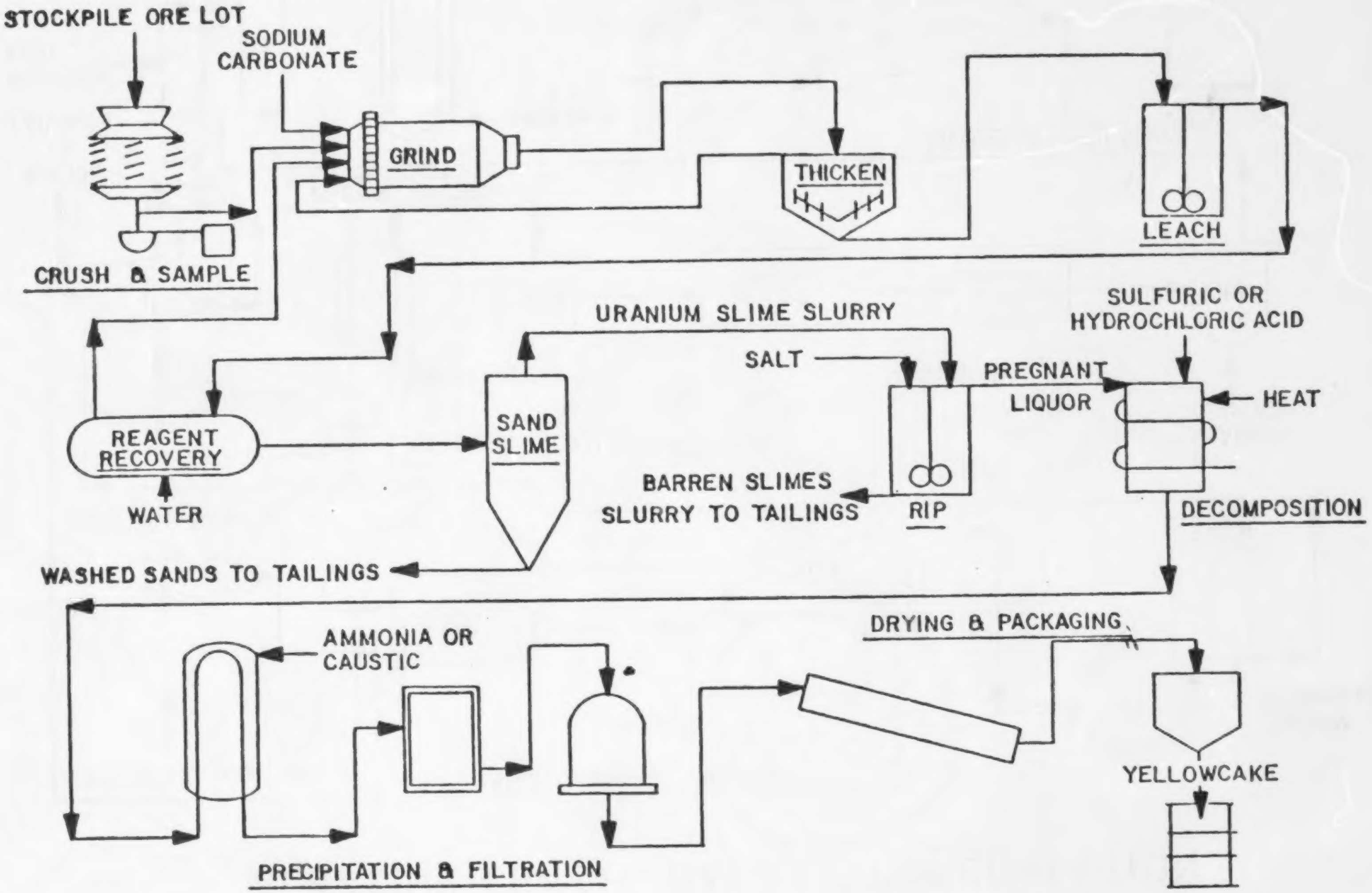

STOCKPILE ORE LOT
CRUSH & SAMPLE
GRIND
WEAK URANIUM SOLUTION
THICKEN
SODIUM CARBONATE
LEACH
CARBON DIOXIDE
CAUSTIC
REGENERATION
FILTR.
TAILING POND H_2O
SOLIDS TO TAILINGS
PRECIP. FILTRATION
ROAST
QUENCH
VANADIUM SOLUTION
SULFURIC ACID
DISSOLUTION
AMMONIA
PRECIP. FILTRATION
SODIUM & AMMONIUM SULFATE
DRYING & PACKAGING
YELLOWCAKE

Source: Reference 2-7

DAMES & MOORE

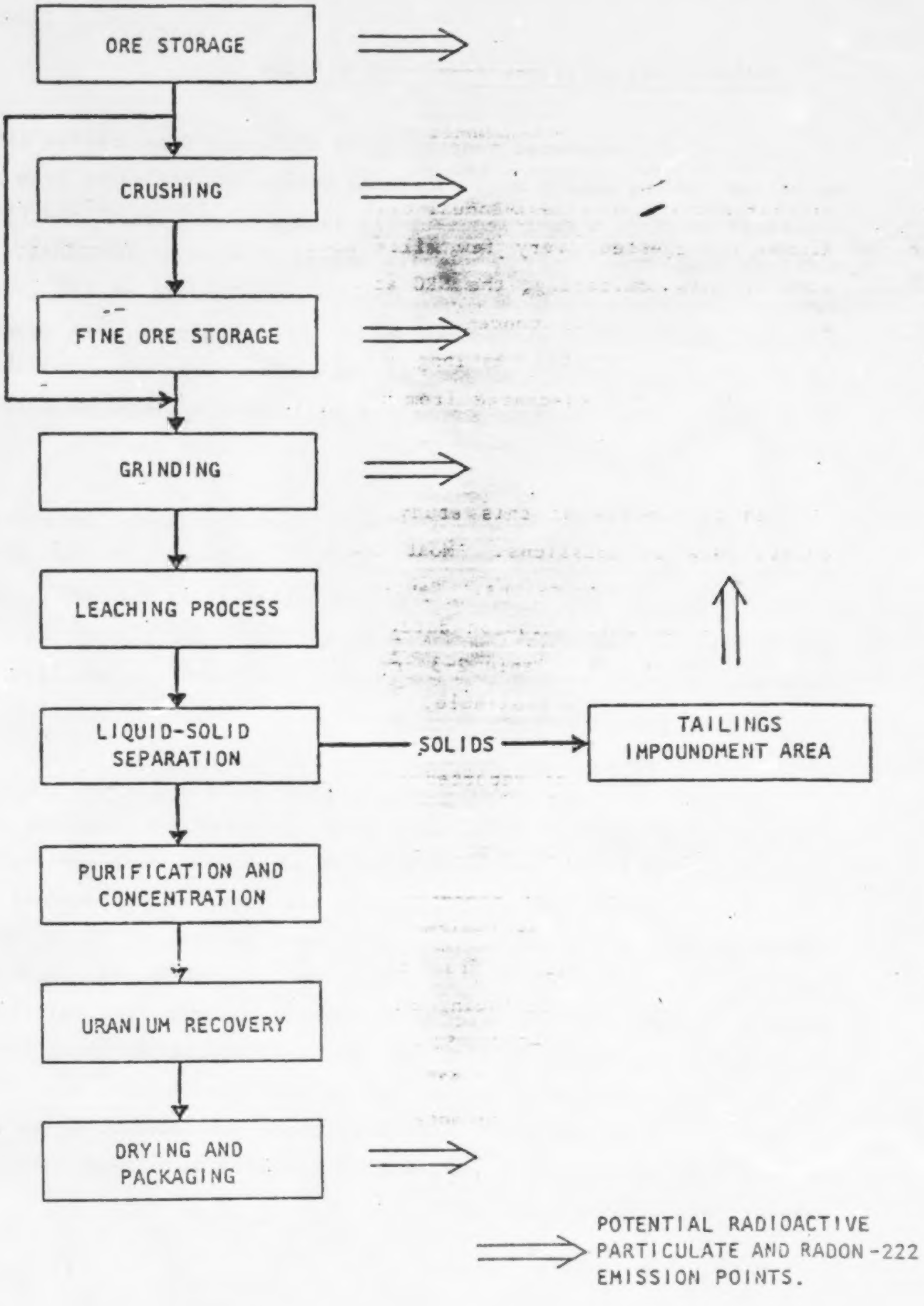
FIGURE 2.8

ALKALINE LEACH, RIP, PRECIPITATION


STOCKPILE ORE LOT
SODIUM CARBONATE
GRIND
THICKEN
LEACH
CRUSH & SAMPLE
URANIUM SLIME SLURRY
SULFURIC OR HYDROCHLORIC ACID
SALT
PREGNANT LIQUOR
HEAT
REAGENT RECOVERY
SAND SLIME
BARREN SLIMES SLURRY TO TAILINGS
RIP
DECOMPOSITION
WATER
WASHED SANDS TO TAILINGS
DRYING & PACKAGING
AMMONIA OR CAUSTIC
YELLOWCAKE
PRECIPITATION & FILTRATION

Source: Reference 2-7

FIGURE 2.9


ORE STORAGE
CRUSHING
FINE ORE STORAGE
GRINDING
LEACHING PROCESS
LIQUID-SOLID SEPARATION
SOLIDS
TAILINGS IMPOUNDMENT AREA
PURIFICATION AND CONCENTRATION
URANIUM RECOVERY
DRYING AND PACKAGING
POTENTIAL RADIOACTIVE PARTICULATE AND RADON-222 EMISSION POINTS.

GENERALIZED URANIUM MILL FLOW DIAGRAM

FIGURE 2.10

Radionuclide Emissions From Uranium Mills

Part of the suggested monitoring of effluents from uranium mills, as defined in Reg. Guide 4.14, includes monitoring effluents from each discharge stack on a semi-annual basis during normal operations.(2-13) Although suggested, very few mills actually monitor effluents. In lieu of this monitoring, the NRC accepts measurements of the average airborne radionuclide concentration at the restricted area boundary for a six month period. As long as the radionuclide concentration is below $MPC_{(a)}$, the discharge from the mill is considered acceptable. (2-14)

In the course of this study, mill operators were contacted to obtain data on emissions. Most operators stated that they do not regularly monitor emissions. Review of documents in the NRC document room, revealed that emission data was available for six of the mills surveyed.(2-15-2-20) Table 2-3 presents this data. No particle size distribution data was available.

The mill data was reported in various units e.g., lbs. U_3O_8/hr, uCi/min and gU_{nat}/hr. These data were converted into release rates for uranium-238, thorium-230, radium-226 of milli-curies per year per ton ore processed. For releases from the pre-grinding circuit discharge points, the three radionuclides were assumed to be in secular equilibrium. Discharges from the dryer and packaging areas were assumed to have the following radionuclide distribution relative to uranium-238: thorium-230, 5% of the uranium-238 activity concentration; and radium-226, 0.02% of the uranium-238 activity concentration.(2-5) It should be noted that these concentrations are based on data from studies which included the obsolete alkyl phosphoric acid solvent extraction process.(2-5)

TABLE 2-3*

Uranium Mill Activity Emission Rates

Mill Owner	Location	Facility	Control Technology	Annual Activity Release per Ton Ore Processed (mCi/yr/ton) U-238	Th-230	Ra-226
Atlas Minerals	Moab, Utah	Dryer	Scrubber	2.99E-4	1.50E-5	5.48E-8
		Packaging	Bag-Collector	1.88E-4	9.32E-6	3.65E-8
Lisbon, Rio Algom	La Sal, Utah	Headframe	u	1.12E-6	1.12E-6	1.12E-6
		Transfer Tower	u	2.98E-6	2.98E-6	2.98E-6
		Crusher	Bag-Collector	1.20E-5	1.20E-5	1.20E-5
		Dryer	Dry Cyclone & Wet Venturi Scrubber	9.88E-5	4.85E-6	<3.80E-8
		Packaging	Bag-Collector	4.40E-5	2.24E-6	<3.80E-8
Lucky McMine, Pathfinder Mines Corp.	Riverton, Wyoming	Dryer	Wet Scrubber	5.45E-4	2.73E-5	1.01E-7
		Packaging	Wet Scrubber	1.40E-4	7.07E-6	2.02E-8
Shirley Basin, Pathfinder Mines Corp.	Shirley, Wyoming	Yellowcake Area	Scrubber Combination	6.94E-5	3.52E-6	<1.85E-8
Highland Uranium Operation	Converse County, Wyoming	Yellowcake Area	Scrubber Combination	1.01E-4	5.07E-6	1.88E-8
Western Nuclear, Inc.	Jeffrey City, Wyoming	Dryer	Wet Scrubber	1.32E-5	5.37E-7	<2.70E-8
		Packaging	Wet Scrubber	1.26E-4	6.45E-6	<2.70E-8

---

u = unknown

* Ref 2-15 - 2-20

Current Control Technology in Uranium Milling

In order to augment data from the literature, a survey of thirteen uranium mills was conducted. Of the thirteen mills from which data was received, eleven are presently operational and two are scheduled to be in operation before 1982. The mills surveyed represent both large scale and small scale operations, and account for approximately 40% of all the operating mills.(2-4) Locations of the mills include New Mexico, Wyoming, Utah, Colorado, and Texas. Two of the operational mills use an alkaline leach process and nine use an acid leach. In the case of the "planned" mills, one of each process type was surveyed. No in-situ leach facilities were surveyed.

The mill operators were contacted by phone and data was obtained whenever possible on; the leach process, the mill capacity (tons of ore process per calendar day), the ore storage control used, the type of crushing-grinding circuit employed, the type of dryer (roaster) control technology used and its efficiency and the controls used on the packaging area and its efficiency. Table 2-4 presents a summary of the data obtained. The stated efficiencies are predominantly manufacturers ratings, as quoted by the operators, for particulates equal to or greater than one micron in diameter.

Several of these individuals requested that the data be used without identifying the facility. As a result, all the facilities cited in Table 2-4 are identified by a letter designation. In the cases where individual operators did not wish to participate in the study, data was obtained from the most recently published literature. (2-21)

The survey revealed that there were no specific control technologies to control possible emissions of radon. In addition, where particulate controls did exist, no data was available on the effect of these controls on the possible discharge of radon. Advance systems of radon-222 control are reviewed in Chapter Four.

TABLE 2-4

Uranium Mill Control Technology Summary

Mill Designation	Leach Process	Capacity (tpd)	Ore Storage Control	Crusher Control Technology and Efficiency	Grinding Type	Dryer Control Technology	Efficiency	Packaging Control Technology	Efficiency
A	Alkaline	1500	u	Water spray system & bag-house collectors -99.%	Wet grind ball mill	Centrifugal-type wet scrubbers	99.18% (1)	Bag-House Collector	99.9%
B	Acid	1300	u	wet scrubber - u	Autogenous dry grind ball mill (2)		Yellowcake facility control: multi-tier wet scrubber -90%		
C	Acid	3000	N.C.	Semi-Autogenous Grinding Circuit			Yellowcake facility control: wet venturi scrubber -99.9%		
D	Alkaline	750	N.C.	Bag-type collector - 95%	Wet grind ball mill	Dry cyclone wet venturi scrubber	99.8%	Bag-house Collector	99.9%
E	Acid	950	N.R.	Impingement & entrainment wet scrubber - u	Wet grind ball mill	Impingement & entrainment wet scrubber	99% (0.4-8 um) 70% (< 0.4 um)	Bag-house Collector	99% (0.2-12 um 70% (< 0.2 um)
F	Acid	3000	N.R.	N.R.	Wet grind rod mill		Yellowcake facility control: bag-house collector - u		
G	Acid	1650	N.R.	Semi-Autogenous Grinding Circuit		Impingement & entrainment wet scrubber	99 +%	Impingement & entrainment wet scrubber	99 +%

u = Type of control and/or efficiency is unknown
N.C. = No controls applied
N.R. = No control required, moisture content >8%

(1) = Measured value
(2) = Control technology associated with grinding is a high velocity wet venturi scrubbers, efficiency 99%.

TABLE 2-4 (cont'd)

Mill Designation	Leach Process	Capacity (tpd)	Ore Storage Control	Crusher Control Technology and Efficiency	Grinding Type	Dryer Control Technology	Efficiency	Packaging Control Technology	Efficiency
H	Acid	1800	N.R.	Semi-Autogenous Grinding Circuit		Wet venturi scrubber and centrifugal flow separator	99.5%	Impingement & entrainment wet scrubber	99 +%
I	Acid	3000	N.R.	Wet centrifugal scrubber - u	Wet grind	Wet venturi scrubber	u	Wet venturi scrubber	u
J	Acid	1700	N.R.	Semi-Autogenous Grinding Circuit		Centrifugal-type wet scrubber	99.05%	Wet centrifugal scrubber	95.0%
K	Acid	1500	N.R.	Semi-Autogenous Grinding Circuit		Wet venturi scrubber	u	Bag-house collector	u
L	Acid	2500	N.R.	Semi-autogenous Grinding Circuit		Yellowcake facility control: Wet venturi scrubbers -95%			
M	Alkaline	600	N.R.	Bag-house collector u	Wet grind	Wet venturi scrubber & a wet fan	u	Bag-house collector	99 +%

u = Type of control and/or efficiency is unknown
N.C. = No controls applied
N.R. = No control required, moisture content >8%

Lastly, generic descriptions of the control devices may be found in Chapter Two, Section 5.

Ore Storage Emission Control Technology

Review of the available data indicates that of the thirteen mills surveyed, eleven do not routinely use any type of control technology to limit particulate emission from the ore storage piles. The two reasons most frequently given for not using any form of control technology are that the natural ore moisture content is greater than 8 percent and that the residence time of the ore in the storage piles is short, approximately four to five days, thereby reducing the extent to which the ore dries. The ore moisture content retained during storage is considered, by most of the mill operators, to be high enough to prevent significant wind erosion.

Ore Crushing Emission Control Technology

Seven of the thirteen mills examined reported to use a grinding circuit that required a pre-sized crushed ore feed. All of the alkaline leach mills surveyed used baghouse collectors, with efficiencies ranging between 95-99 percent. Of the remaining four mills (all acid leach), three used some type of wet scrubber system. The efficiencies of these systems are unknown.

One mill facility reported a crusher without a method of control technology. The operator claimed that the high ore moisture content (20-25%) minimized dust generation during the crushing operation, negating the necessity of a control device.

Ore Grinding Emission Control Technology

Only one mill used a dry grinding circuit that required a control technology. The control used is a water spray system in conjunction with a baghouse collector. The cited efficiency was 99%. The balance of mills use wet grind circuits (ball or rod) or semi-autogenous wet grind circuits. Use of any form of a wet grinding circuit excludes the need for a particulate control technology as dust generation is inherently minimized.

Drying and Packaging Control Technology

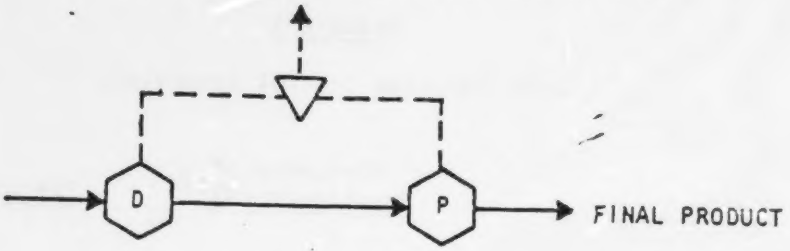
Conversations with supervisory personnel at the mills indicated that at least seven of the facilities use a yellowcake control system in which the gaseous effluents (treated or untreated) from the drying and packaging operations are passed through a common emission control system prior to discharge to the environment. Unfortunately, exact descriptions could be obtained for only three mill systems. Figure 2-11 presents generalized flow diagrams of the various yellowcake control systems for which descriptions were obtained. The most frequently used control device determined by the survey was a wet scrubber. The cited efficiencies of these yellowcake control systems ranged from 90-99.9%.

The remaining mills used emission control equipment whose treated effluents are discharged through individual stacks, e.g., dryer and packaging stacks. Of these all but one reported using a type of wet scrubber to treat the gaseous effluent from the dryer facility. The three types of wet control systems used were centrifugal scrubbers, venturi scrubbers, and impingement and entrainment scrubbers. Table 2-5 presents a summary of the data obtained on dryer emission control technology resulting from this survey. The venturi wet scrubber is the control technolgy with the highest frequency of occurrence in the survey and has the highest quoted efficiency, 99.8%.

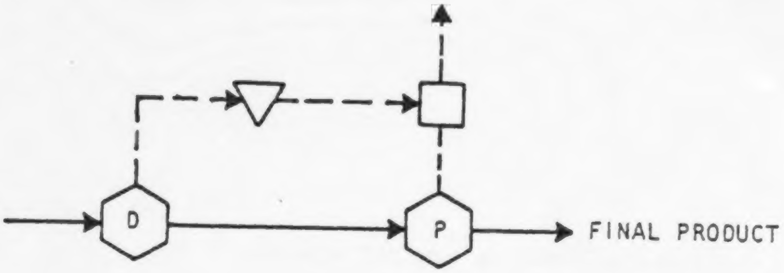
Review of the data obtained from the uranium mills indicates that the types of technologies used to control packaging area emissions are

GENERALIZED FLOW DIAGRAM FOR COMMON YELLOWCAKE EMISSION CONTROL SYSTEMS

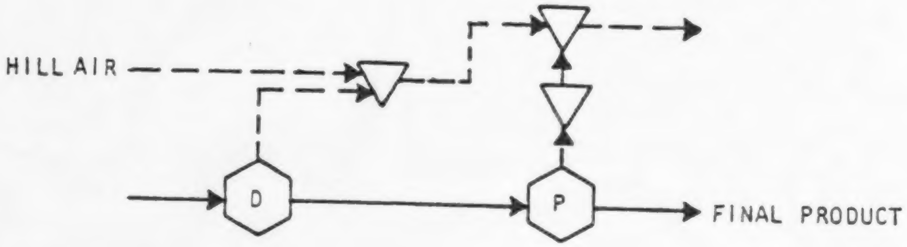
SIMPLE YELLOWCAKE CONTROL SYSTEM


D
P
FINAL PRODUCT

DUAL COMPONENT YELLOWCAKE CONTROL SYSTEM


D
P
FINAL PRODUCT

COMPLEX YELLOWCAKE CONTROL SYSTEM


HILL AIR
D
P
FINAL PRODUCT

KEY:

⬡ D DRYER (ROASTER)

⬡ P PACKAGING FACILITY

- - -→ GASEOUS EFFLUENT

▽ WET SCRUBBER

□ BAG-HOUSE COLLECTOR

——→ YELLOWCAKE PATHWAY

DAMES & MOORE

FIGURE 2.11

TABLE 2-5

Dryer Emission Control Technology (1)

System Type	Frequency of Occurrence (%)(2)	Efficiency Range (3)
Centrifugal Scrubber	16.7	99.05 - 99.18
Venturi Scrubber	58.3	99.0 - 99.8
Impingement and Entrainment Scrubbers	25.0	99 + (4)

---

(1) Includes yellowcake control systems
(2) Includes 12 of 13 mills surveyed
(3) For particles with diameters of greather than 1 micron
(4) Efficiency estimates from operators were all "better than 99%."

bag-house collectors, wet venturi scrubbers, impingement and entrainment scrubbers, and wet centrifugal scrubbers. Table 2-6 presents a summary of the controls, the frequency of use as determined by the survey and the quoted efficiency range.

A bag-house type collector was found to be the emission control with the highest frequency of occurrence by the mills surveyed. It should be noted, however, that venturi scrubbers and bag-house collectors both had the highest quoted mass collection efficiency, 99.9%.

Control Technology Residuals

The residuals from the control technologies previously discussed consist of primarily ore dust or yellowcake. As this is either raw material or final product, it is recovered. Therefore residuals do not present disposal problems.

Tailings Controls

As stated previously, solids are separted from the pregnant solution by use of a counter current decantation circuit. The separated solids are transferred to the tailings impoundment area where they are usually segregated, by mechanical or natural means, into sands (> 200 mesh) and slimes (< 200 mesh) fractions.

The slimes fraction is estimated to be approximately 20% by weight of the solids discharged to the tailngs area. This fraction of the tailings contains between 80-85% of the total activity released to the impoundment area.(2-11)

During the operational stage of the mill a water cover is maintained over the slimes fraction of the tailings while the sand portion is permitted to dry. The drying sands are, therefore, the

TABLE 2-6

Packaging Area Control Technology(1)

System Type	Frequency of Occurrence (%)(2)	Efficiency Range (3)
Bag-House Collectors	46.2	99 - 99.9
Venturi Scrubbers	23.1	99.5 - 99.9
Impingement and Entrainment Scrubbers	23.1	99+
Centrifugal Scrubbers	7.7	95.0(4)

---

(1) Includes yellowcake control systems
(2) Includes 13 of 13 mills surveyed
(3) For particles with diameters of greater than 1 micron
(4) Only one facility used a wet centrifugal scrubber.

primary source of particulate and gaseous emissions, from the tailings area. The means of controlling particulate emission include water spraying, physical stabilization, chemical stabilization and/or vegetative stabilization.(2-22 to 2-27)

Physical stabilization methods include use of soil covers, smelter slag covers, harrowing of straw into the upper inches of the tailings, and bark and straw covers. Chemical stabilization involves the use of chemicals which form wind and water resistant crusts when exposed to tailings and the air. The chemicals used in this technique include amines, limes, cationic neoprene emulsion, elastomeric polymers, and lignosulfonates.

Use of vegetation as a stabilizing agent requires extensive preparation of the upper portion of the tailings to help insure plant germination. Such preparation includes increasing plant nutrient content, removal of salts and heavy metals, and increasing beneficial microbial populations in the soil.

Discussions with various uranium mill operators indicates that the use of a water spray system or physical stabilization with some vegetative stabilizations are the techniques most widely used. The estimated efficiencies for reducing radioactive particulate emissions are 85 percent and 100 percent for water spray and physical reclamation respectively. The effects of these techiques on radon-222 emission is unknown.

Control Technology Costs

Bag-House Collectors

Conversations with various uranium mill superintendents indicated that there are three general types of bag-house collectors employed in the industry. These are: 1) an intermittent operation, pressure bag-house with a mechanical shaker, 2) a continuous operation, pressure bag-house with a mechanical shaker and 3) a continuous operation, pressure bag-house with a pulse jet cleaning system. A fourth type of bag-house, a continuous operation, pressure bag-house with reverse air flow cleaning was included for comparison.

The following assumptions were made in developing the cost summary presented in Table 2-7:

- Units are constructed of carbon steel and are not insulated.
- The cost of auxillary equipment, e.g., duct work fans, stack, mechanical collector and pressure gauges, is not to be included.
- The fabrics used for dust emission control are felt and polypropylene with air to cloth ratios (ACR) of 3:1 and 5:1 respectively.
- Installation costs are approximately 75% of the equipment purchase price.(2-27)
- Maintenance costs are approximately 2% of the equipment purchase price.(2-27)

Based on the above assumptions, costs were developed for flow rates of 2000, 5000, and 7000 SCFM for each of the four cases described. The results are presented in Table 2-7 for bag-house collectors using felt fabric and polypropylene fabric filters. The costs were developed as a function of price per square foot of cloth fabric and bag-house type and include the basic bag-house without bags, ten foot clearance and inlet and exhaust manifolds. It is assumed that the bag-houses were to be designed for a 12" water gauge pressure differential. The costs presented are in 1975 dollars.

TABLE 2-7

Bag-House Collector Cost Summary[a]

		Costs (Felt Material)(b)				Cost (Polypropane Material)(b)			
Type #	Description(a)	Equipment	Installation	Maintenance(c)	Bag(d)	Equipment	Installation	Maintenance(c)	Bag(d)
#1	bgh. w/m.s., intermit. oper., pres.								
	2000 scfm	4000	3000	90	300	3550	2700	75	240
	5000 scfm	6200	4650	125	700	4510	3400	90	600
	7000 scfm	7200	5400	145	960	5150	3900	105	840
#2	bgh. w/m.s., cont. op., pres.								
	2000	8100	6080	165	300	7000	5250	140	240
	5000	11100	8350	225	700	8800	6600	180	600
	7000	13000	9750	260	960	10000	7500	200	840
#3	bghs w/pulse jet, cont. op., pres.								
	2000	9610	7210	195	395	7300	5500	150	260
	5000	16210	12200	325	920	11260	8450	225	650
	7000	20500	15400	410	1260	13900	10450	280	910
#4	bghs w/reverse air, cont. op., pres.								
	2000	24250	18190	485	265	23340	17510	470	200
	5000	26850	20140	540	615	24900	18700	500	500
	7000	28540	21410	570	840	26000	19500	520	700

(a) To convert to 1978 dollars multiply by 1.21
(b) See text, page II.2-34 for a description
(c) Costs are presented in 1975 dollars

(d) Annual cost
(e) Cost per replacement

No data on the operational costs of the bag-house are presented.

Wet Scrubbers Control Technology

The other major control is the wet scrubber. Three general types of wet scrubbers are used, the venturi type, the centrifugal and the impingement and entrainment type. The cost data developed in this section is based on the extrapolation of quoted purchase price data for particular size wet scrubbers using the following equation: (2-28)

$$C_B = C_A \frac{V_B}{V_A}^{0.6}$$

where:

C_B = The unknown cost parameter of interest for unit B.
C_A = The known cost parameter of interest for unit A.
V_A, V_B = The influent flow rtes of units A and B respectively.

The data on purchase costs, installation and maintenance costs were developed using the following assumptions:

- All three types of scrubbers, regardless of flow rate, are constructed of 1/8" carbon steel.
- The fan is an integral part of the unit and is, therefore, included in the purchase price.
- The venturi systems considered are all medium energy systems.
- The purchase price does not include the cost of any auxillary equipment such as duct work, linings, quenchers, stacks, or monitoring gauges.

- All of the units are of standard design and are factory assembled.

- For the venturi scrubbers, the purchase price does not include a separator.

- Installation and annual maintenance costs are 140% and 13% of the purchase price respectively.

- Annual power and water costs can be extrapolated from Reference 16 using equation 2.2-1.

Table 2-8 presents a summary of the cost data developed for the various type scrubbers. Review of the data indicates that of the three types considered, the wet venturi scrubbers (excluding separator) are the most expensive units to purchase, install, maintain, and operate.

Summary

Conversations with operators at thirteen uranium mine/mill facities and review of the available literature dealing with the emission control technologies used in the uranium industry, have indicated the following:

- No controls are currently used to specifically limit radioactive particulate and/or radon-222 emissions from surface or underground mines.

- The effects of mine safety procedures, used to reduce radon-222 concentrations in working areas or leakage from worked out areas, on radioactive particulate and radon-222 emissions from the mine are unknown.

TABLE 2-8

Wet Scrubber Cost Summary

Scrubber Type	Flow Rate (CFM)	Purchase(c) Cost($)	Installation(d) Cost($)	Maintenance(e) Cost ($/yr)	Power Cost(f) ($/yr)	Water Cost(f) ($/yr)
Venturi(a)	1000	5610	7900	730	2270	290
	2200	9000*	12600	1200	3640	470
	4500	13800	19400	1800	5580	720
	9000(b)	21000	29400	6560	8460	1830
Wet Centrifugal	1000	3600	5000	660	490	160
	2000	5700*	8000	1040	740	240
	4500	8800	12300	1600	1200	400
Wet Impingement & Entrainment	1000	3240	4500	430	550	210
	2000	4900*	6900	640	830	310
	4500	7900	11100	1460	1450	510

(a) Medium energy venturi without separator
(b) Included since flow rate was the maximum encountered
(c) Purchase price was extrapolated from quoted prices (indicated by *) using e.q. 2.2-1, 1979 dollars
(d) Annual cost assumed to be 140% of purchase price, 1979 dollars (2-27)
(e) Annual cost assumed to be 13% of purchase price, 1979 dollars (2-27)
(f) Costs extrapolated from Ellison, WM (1971), 1971 dollars, to convert to 1978 dollars multiply by 1.21

- Very few operators, if any, use any form of control to limit fugitive dust emission from the ore storage piles.

- The systems used to control particulate emissions from the mills are bag-house collectors and wet scrubbers.

- The control technologies are used either as independent systems, e.g., separate discharge stacks, or in conjunction as a yellowcake control system, e.g., common discharge stack.

- Operating facilities do not routinely measure a control system efficiency. However, the quoted removal efficiencies for particles with diameters equal to or greater than 1 micron for bag-house collectors and wet scrubbers ranged from 99-99.9% and 95-99.9% respectively.

- The annual release per ton of ore processed for the two types of controls were in the range of 10^{-5} - 10^{-4} mCi of uranium-238. Data on particulate activity release is not readily available.

- The costs of the bag-house collector are a function of flow rate, fabrics filter material, operational mode and cleaning mechanism.

- The costs of a wet scrubber are a function primarily of type of scrubber (venturi, centrifugal or impingement and entrainment) and flow rate.

- Comparison of control technologies cannot be made using the data presented.

- No data is currently available from the mill operators on the operational costs of the control equipment.

- No data is available on the rate and amount of radon-222 discharge from the mine and mill facilities.

- The effects of the particulate control technologies used at the mills on radon-222 emissions are unknown.

Conclusions

Identification of an exemplary control technology used by the uranium industry to control radioactive particulate and radon-222 emission cannot be accomplished at this time. Insufficient data is currently available on: the removal efficiencies of the controls as a function of influent particle size; the particle size distribution of the influent; the operational costs associated with the controls; and the types and costs of auxillary equipment used.

REFERENCES

II.2-1 Bureau of Mines. Mineral Facts and Problems. Bulletin 667, 1975.

II.2-2 Sisselman, R. "Uranium Fever in the U.S. is Spreading as Explorationists Step Up the Search." Engineering and Mining Journal, Vol. 179, No. 11, November, 1978.

II.2-3 Jackson, D. "Wyoming Approaches New Mexico in U_3O_8 Production and Reserves." Engineering Mining Journal, Vol. 179, No. 11, November, 1978.

II.2-4 U.S. Nuclear Regulatory Commission. Generic Environmental Impact Statement on Uranium Milling. NUREG-0511, April, 1979.

II.2-5 Sears, M.B., et al. Correlation of Radioactive Treatment Costs and the Environmental Impacts of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "As Low As Practicable" Guides - Milling of Uranium Ores. Vol. 1, ORNL-TM-4903, 1975.

II.2-6 U.S. Department of Health, Education, and Welfare. Bureau of Radiological Health. Radiological Health Handbook, Revised Edition. January, 1970.

II.2-7 Morse, J.G., Curtin, M.S. Colorado Energy Resources Handbook, Volume 3: Uranium. Golden, Colorado: Colorado School of Mines, 1977.

II.2-8 Kown, B.T., Vonder Mast, V.C., Ludwig, K.L. Technical Assessment of Radon-222 Control Technology for Underground Uranium Mines. U.S. Environmental Protection Agency, Office of Radiation Programs, Division of Technology Assessment, Contract No. 68-02-2616. Prepared by Bechtel National, Inc., San Francisco, CA, 1979.

II.2-9 Larson, W.C. Uranium In Situ Leach Mining in the United States. Bureau of Mines, IC-8777, 1978.

II.2-10 30 CFR 57.5, Mine Safety and Health Administration. 1975.

II.2-11 Clark, D.A. State-of-the-art: Uranium Mining, Milling, and Refining Industry. U.S. Environmental Protection Agency, Office of Research & Development, EPA-660/2-74-038, June, 1974.

II.2-12 Hazen, W. "Uranium Milling," in Uranium Resource/Technology Update, Seminar Proceeding, Ed. J.G. Morse. Golden, Colorado: Colorado School of Mines, March 14, 1978.

II.2-13 U.S. Nuclear Regulatory Commission. Measuring, Evaluating, and Reporting Radioactivity in Releases of Radioactive Materials in Liquid and Airborne Effluents from Uranium Mills. Regulatory Guide 4.14, 1977.

II.2-14 U.S. Nuclear Regulatory Commission. Region IV, Texas. Personal Communication, G. Brown, January, 1979.

II.2-15 U.S. Nuclear Regulatory Commission. Docket File 40-3453. Personal Communication, L.C. Rouse, April 20, 1978.

REFERENCES (cont'd)

II.2-16 U.S. Nuclear Regulatory Commission. Docket File 40-8084. Personal Communication, L.C. Rouse, March 30, 1978.

II.2-17 U.S. Nuclear Regulatory Commission. Docket File 40-2559. Personal Communication, L.C. Rouse, August 18, 1979.

II.2-18 U.S. Nuclear Regulatory Commission. Docket File 40-6622. Personal Communication, L.C. Rouse, June 27, 1978.

II.2-19 U.S. Nuclear Regulatory Commission. Docket File 40-8102. Personal Communication, L.C. Rouse, April 14, 1978.

II.2-20 U.S. Nuclear Regulatory Commission. Docket File 40-1162. Personal Communication, L.C. Rouse, April 18, 1979.

II.2-21 Atlas Corp. Minerals Division. Safety Analysis Report - Moab Uranium Mill. Revision, August, 1975.

II.2-22 Bureau of Mines. Chemical Stabilization of the Uranium Tailings at Tuba City, Arizona. RI 7288, August, 1969.

II.2-23 Nielson, R.F. & Peterson, H.B. Treatment of Mine Tailings to Promote Vegetation Stabilization. Utah State University. Agricultural Experiment Station Bulletin 485, June, 1972.

II.2-24 Shirts, M.B. & Bilberg, J.H. Stabilization Methods for the Reclamation of Tailings Ponds, Presented at Land Scraping and Land Use Planning as Related to Mining Operations. Adelarde, Australia, March, 1976.

II.2-25 Dean, K.C. & Havens, R. "Stabilizing Mineral Wastes." Engineering Mining Journal, Volume 23, No. 4, April, 1971.

REFERENCES (cont'd)

II.2-26 Reynolds, J.F., Cvik, M.J., and Kelly, N.E. *Reclamation at Anaconda's Open-pit Uranium Mine as Presented at the First Annual General Meeting of the Canadian Land Reclamation Association, Ontario, Canada*. November, 1976.

II.2-27 *The Fabric Filter Manual,* Volume 3, Chapter XI, Section 3.1, Northbrook, Illinois: The McIlvaine Co., 1979.

II.2-28 Ryan, A.D., *et al.* *Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing, "As Low as Practicable" Guides - Appendix A. Preparation of Cost Estimates for Volume 1: Milling of Uranium Ores. Vol. 2.* ORNL-TM-4903, May, 1975.

CHAPTER II

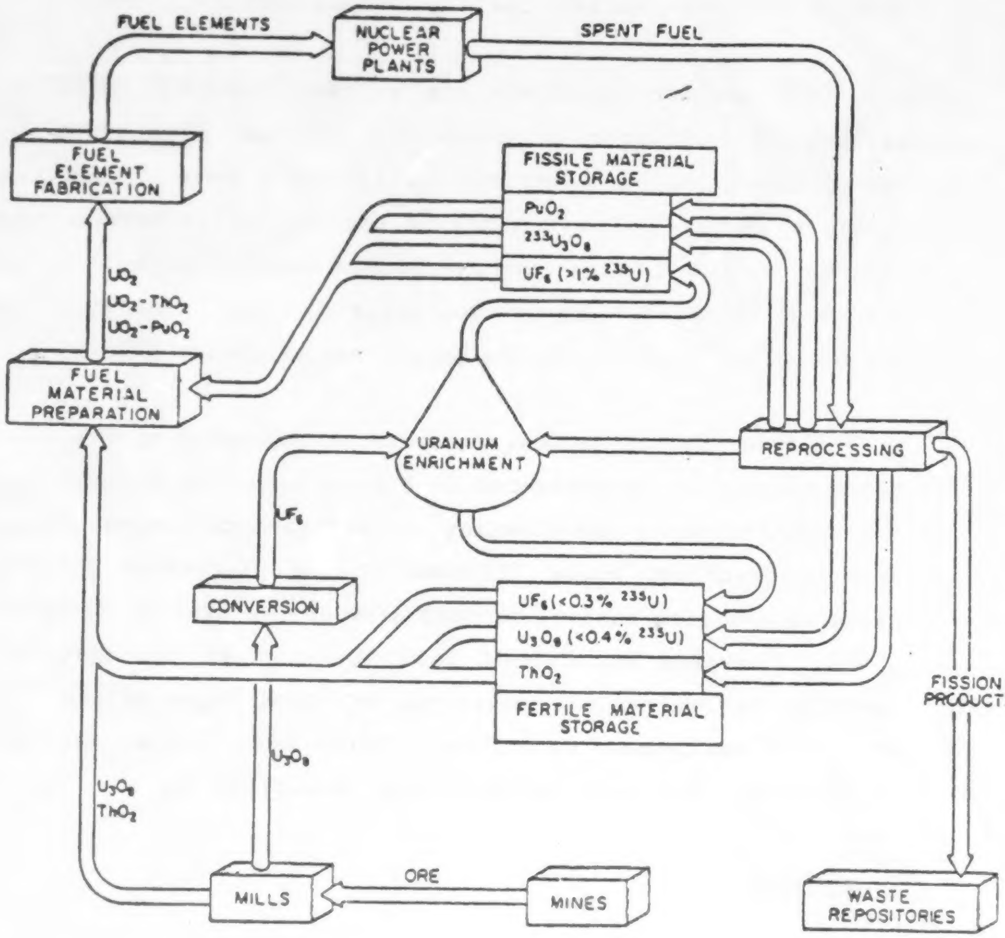
Section 3: Other Nuclear Fuel Cycle Facilities

This section considers the current airborne emission control technologies utilized in commercial nuclear fuel cycle facilities other than uranium mines and mills which were considered in the previous section. The majority of the facilities considered here are licensed by the U.S. Nuclear Regulatory Commission (NRC) in accordance with Code of Federal Regulations Title 10 (3-1). The other facilities are owned and operated by the Department of Energy (DOE).

A flow diagram showing the interrelationship of the nuclear fuel cycle facilities is presented in Figure 3.1. The general approach in the application of air cleaning technologies to nuclear facilities is briefly described below followed by the discussion of the current airborne emission control technologies at the uranium conversion (UF_6) plants, uranium enrichment facilities, fuel fabrication plants, central station nuclear power plants, fuel reprocessing facilities, and waste management facilities. Other NRC-licensed facilities such as research and test reactors are considered in the next section.

Background

Air cleaning systems are provided to protect the public and plant operating personnel from airborne radioactive particles and gases which are, or could be, generated or released from operations conducted in facilities that handle material containing radioactivity. Such systems are characterized by operation at very high contaminant collection levels, generally orders of magnitude greater than those exhibited by air cleaning systems employed in other commercial, industrial, or pollution control applications.


FUEL ELEMENTS
NUCLEAR POWER PLANTS
SPENT FUEL
FUEL ELEMENT FABRICATION
FISSILE MATERIAL STORAGE
PuO_2
$^{233}U_3O_8$
UF_6 (>1% ^{235}U)
UO_2
UO_2-ThO_2
UO_2-PuO_2
FUEL MATERIAL PREPARATION
URANIUM ENRICHMENT
REPROCESSING
UF_6
CONVERSION
UF_6 (<0.3% ^{235}U)
U_3O_8 (<0.4% ^{235}U)
ThO_2
FERTILE MATERIAL STORAGE
FISSION PRODUCTS
U_3O_8
U_3O_8
ThO_2
ORE
MILLS
MINES
WASTE REPOSITORIES

THE NUCLEAR FUEL CYCLE
LIGHTWATER REACTORS

FIGURE 3.1

The kind of air cleaning system depends on the process or facility to be controlled. It is possible to have a single control system sufficient to meet applicable criteria for an entire facility. However, usually the processes at nuclear facilities can be separated into regions based on either the amount of radioactivity handled or the expected airborne radioactive concentrations, or the specific radionuclides handled in each region. In such a process the primary line of defense providing confinement of radioactive materials is to separate the process area into several zones each of which is at a lower pressure but higher potential radiotoxicity than the preceeding zones. By doing so, the air will flow unidirectionally towards the location of highest potential contamination. The air zone system and the airborne emission control technology applied to the ventilation system of each zone, i.e., its communication with other zones and/or unrestricted areas, are dictated by both the nature of the contaminant and the nature of the work area. The zonation system and the corresponding control technology must meet the applicable criteria for the airborne radioactive concentrations given in Appendix B of 10 CFR 20 (3-1), as well as the "as low as reasonably achievable" requirements which, at least for the light water reactors, restrict gaseous and airborne particulate effluents to levels corresponding to the design objective limits set forth in Appendix I of 10 CFR 50 (3-1).

One possible zoning of a facility based on the radiotoxicity of the materials handled is given in Nuclear Air Cleaning Handbook (ERDA-76-21), formerly known as ORNL/NSIC-65 (3-2). This zoning is summarized below. Radioactive materials are grouped as shown in Table 3-1 with respect to relative inhalation hazard. Based on this classification, applicable design criteria and guides shown in Table 3-2 are set for each hazard class. Based on these two tables, guides can then be set for "zones" as shown in Table 3-3. A building or facility can then be divided into confinement zones with respect to the hazard classes shown in Table 3-1 based on the guides shown in Table 3-3. By means of this procedure, it is possible to establish a basis for

TABLE 3-1

Classification of Isotopes According to Relative Radiotoxicity Based on Inhalation Hazard[a] Amounts (Ci) Equivalent to 1 g of Pu-239 (HEP)[b]

Class 1 (Very high radiotoxicity) HEP $\leq$ 0.07	Sr-90 + Y-90, Po-210, Po-210 + Bi-210, Ra-226, Th-228, U-232, Np-236, Pu-238, Pu-240, Pu-241, Am-241, Am-242m,[d] Cm-242, Am-243, Cm-243, Cm-244, Cm-245, Cm-246, Cm-247, Bk-249, Cf-249, Cf-250, Cf-251, Cf-252
Class 2 (High Radiotoxicity) HEP = 0.86 to 17	Na-22, P-32, Ca-45, Sc-46, V-48, Fe-59, Co-58, Co-60, Ni-63, Zn-65, Rb-86, Sr-89, Y-91, Zr-95 + Nb-95, Ru-103 Ru-106 + Rh-106, Ag-105, Ag-110, Cd-109 + Ag-109, Cd-115, In-114, Sn-113, Sb-122, Sb-124, Sb-125, I-131, Cs-134, Cs-137 + Ba-137, Ba-140 + La-140, Ce-144 + Pr-144, Pm-147, Sm-151, Eu-152, Eu-154, Tm-170, Hf-181, Ta-182, Ir-192, Hg-203, Tl-204, Bi-210, At-211, U-233[c], Th-234 + Pa-234, Np-237, Pu-242
Class 3 (Moderate radiotoxicity) HEP = 22 to 220	Be-7, Na-24, S-35; K-42, Ca-47, Sc-47, Sc-48, Mn-52. Mn-54, Fe-55, Mn-56, Cu-64, Ga-72, As-74, As-76, As-77 Se-75, Br-82, Sr-85, Y-90, Nb-95, Mo-99, Pd-103 + Rd-103 Rh-105, Pd-109, Ag-111, Cd-115, Sb-122, Te-127, Ba-131, La-140, Ce-141, Pr-142, Pr-143, Nd-147, Ho-166, Sm-153, Ho-170, Lu-177, W-181, W-185, W-187, Re-183, Re-186, Os-191, Ir-190, Ir-192, Ir-194, Pt-191, Pt-193, Au-196, Au-198, Au-199, Hg-197, Tl-200, Tl-201, Tl-202, Ac-227, pure U-233, U-234
Class 4 (Slight radiotoxicity) HEP > 430	H-3, C-14, F-18, Cl-36, Ar-37, Cr-51, Ni-59, Ge-71, Kr-85, Tc-98, Tc-99, Ru-97, Rh-103, Te-129, I-129, I-132, Xe-133, Pb-203, U-235, U-236, natural thorium, U-238, natural uranium

---

(a) These values are based on inhalation and immersion (for inert gases) hazard only. Other factors must be considered are criticality, chemical toxicity and reactivity, and pyrophoricity.

(b) HEP = hazard equivalent plutonium.

(c) <500 ppm U-232

(d) Underlined isotopes are fissile and require special consideration for nuclear safety.

Note: HEP = $(2.16\times10^{9})(CG\times A)$ where
CG = uCi/ml for 40-hr week, i.e., the concentration guide for maximum dose allowable for 40-hr week
A = g/Ci or 0.1, whichever is greater.

Source: Procedures and Practices for Radiation Protection, Health Physics Manual, Oak Ridge National Laboratory, Oak Ridge, Tenn.

TABLE 3-2

Hazard Classification of Radioisotopes

Hazard Class	Hazard	Concentration Guide, Air[a] (Ci/liter)	Amount of Radioactive Materials Permitted[b] (uCi)
1	Very High	$\leq 10^{-13}$	0.1
2	High	10^{-13} to 10^{-11}	1.0
3	Moderate	10^{-11} to 10^{-9}	10.0
4	Negligible	$\leq 10^{-9}$	100.0

(a) Concentration guides specified in 10 CFR 20.

(b) Amount of radioactive material that can be handled without special protection for personnel.

TABLE 3-3[a]

Zoning of Facilities Based on Radiotoxicity of Materials Handled

Radiotoxicity of Isotopes	Quantity of Material Handled vs radiotoxicity			
	Zone 1	Zone 2	Zone 3	Zone 4
Very High[b]	> 10 mCi	10 uCi-10 mCi	0.1 uCi- 10 uCi	0-0.1 uCi
High	> 100 mCi	100 uCi-10 mCi	1.0 uCi-100 uCi	0-1.0 uCi
Moderate	> 1 Ci	1 mCi- 1 Ci	10 uCi-1 mCi	0-10 uCi
Slight	> 10 Ci	10 mCi-10 Ci	100 uCi-10 mCi	0-100 uCi

(a) Source: Procedures and Practices for Radiation Protection, Health Physics Manual, ORNL, Oak Ridge, Tenn.

(b) There is an upper limit to the quantity of transuranium isotopes which should be approved for glove box operations; see (Ref 3-2).

ventilation and air cleaning requirements in various parts of a building or plant, and design the appropriate nuclear air cleaning system. One possible way to define the zones, with respect to function and permitted occupancy, given in (3-2), is as follows:

Zone 1 is the interior of a glove box, hot cell, or other containment for handling highly radioactive material. Zone 1 areas must be completely isolated by physical barriers from neighboring work areas. Containment features must prevent the spread of radioactive material within and release from the building under both normal and upset conditions up to and including the design basis accident for the facility. The exhaust system must be independent of the systems serving other areas. A High Efficiency Particulate Air (HEPA) filter is recommended for the air inlet and two independently in-place testable stages of HEPA filters are recommended for the exhaust stream. Protective clothing, respirators and/or gas-masks (as specified by the responsible health physicist) are required for personnel entry into zone 1 areas.

Zone 2 is generally a hot cell service or maintenance area, a glove box operating area, or any other area where high levels of radiation could be present. Continuous monitoring of airborne radioactive material is required. Restricted access areas are generally considered to be Zone 2. It is recommended that sufficient recharge air be supplied such that the airflow into the glove boxes or hoods are a minimum of 100 linear feet per minute (fpm) and 200 fpm for particularly hazardous set-ups (e.g., hot plate usage). The entry zone for zone 2 should be provided with a personnel clothing-change room or air lock. Generally laboratory coats and shoe-coverings should be required in zone 2 areas.

Zone 3 areas are usually "cold" (contamination absent) areas, but they are subject to periodic introduction of small quantities of contamination. These can be hot cell operating areas, general chemical laboratories, and other general working areas. Routine airborne radiation monitoring is required.

Zone 4 areas include office areas and other "cold" work areas. Special protective clothing is not specified for zone 4 areas.

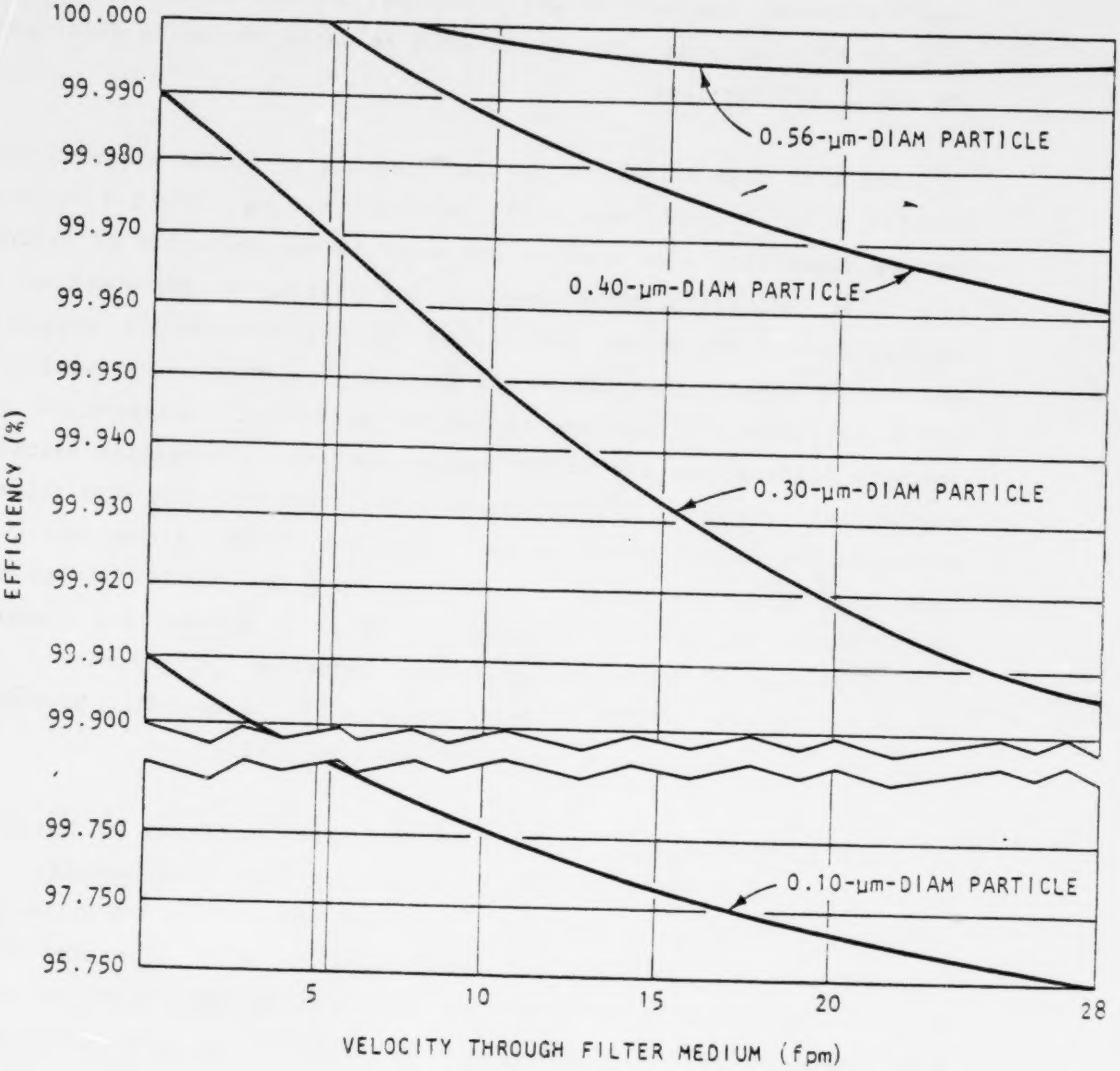
The pressure zonation employed at nuclear facilities is designed such that the airflow is from areas of little or no potential contamination towards areas of higher potential contamination. The flow rate of air must be sufficient to provide the necessary cooling and dilution as well as to prevent backflow into areas of lower potential contamination. A minimum of 0.1 inches (water gauge) pressure differential between zones is recommended. Higher pressure differentials (between 0.3 and 1.0 inches water gauge) are generally recommended between zone 1 and 2 areas.

System space and flexibility are important design considerations for nuclear air cleaning systems. It is advantageous to incorporate advanced air cleaning technologies into the original design of a building since adding ductwork, fans, and dampers to existing facilities may result in exchanging good system and aerodynamic design for adaptability. The accessibility of the system components for maintenance greatly influences the annual operating costs. Another major consideration in the design of nuclear air cleaning systems is the buildup of radioactive materials on ductwork, dampers, and the HEPA filters; this buildup may result in significant health physics considerations with respect to exposure times for maintenance work and filter changing. The air cleaning system should be designed to allow for easy maintenance access as well as relatively simple system modification. The design of nuclear air cleaning systems is dependent upon the characteristics of the expected contaminants flowing through the system such as specific activity, toxicity, viscidity, particle size distribution, and corrosiveness.

The degree to which particulate removal is required in nuclear facilities is generally significantly greater than that reached by conventional particulate control technologies. Even the best of the common air filters used in conventional air cleaning applications exhibit number efficiencies of no greater than 83% to 86% (decontamination factors of 6 to 7) for submicron particles, i.e., those having an aerodynamic diameter of less than 1 micrometer (3-2). Furthermore, most of the efficiencies quoted for conventional air filters are mass efficiencies, e.g., the system removes 98% of the mass influent. However, mass accounts for only a small number of the total of fine particulates existent in typical urban industrial air. Although less than one percent by weight of particles in urban air are less than 0.05 um in diameter, the particle count in this fraction is 99.9999 percent of the total count in typical urban air (3-2). Therefore, High Efficiency Particulate Air (HEPA) filters are utilized in nuclear facilities.

A sample air cleaning equipment specification for a HEPA filter is provided in Appendix II-A. All HEPA efficiencies are given as number efficiencies, e.g., it removes 90% of all particles with an aerodynamic diameter greater than 0.1 um. Providing that HEPA filters have been properly installed so that a bypass airflow around the filter bank is not possible, number efficiencies of 99.95% or greater for 0.3 um size particles are attainable. The efficiencies depend on the flow rate through the filter, as well as the gaseous stream to be filtered. The dependence of the efficiencies on the particle size and the flow rate is illustrated in Figure 3.2.

For systems with more than one HEPA filter in series, the system efficiency can be calculated from the individual efficiencies, e.g., with two HEPA filters in series each with an efficiency of 99.97% for particles greater than 0.3 um, the system efficiency would theoretically be 99.999991% for particles greater than 0.3 um, provided that the system has been properly installed. In general, efficiencies vary



HEPA FILTER EFFICIENCY VERSUS FLOW RATE

Source: Reference 3-2

DAMES & MOORE

FIGURE 3.2

with the system, the date it was installed, and how it was installed. In-place efficiency testing is the only reliable method to determine the actual efficiencies.

The most used method for in-place testing of filter efficiencies involve dioctyl phthalate (DOP) aerosol testing. This in-place testing capability also enables the accurate determination of filter life. At facilities where in-place DOP testing is performed on a regular basis, the actual particulate removal efficiencies attained are usually greater than the values generally reported by the vendors. Where in-place DOP testing cannot be performed, observation of pressure drops across the filter medium are made to determine whether significant loading or filter breaching has occurred. The HEPA filter manufacturers recommend replacement when resistance reaches the 2.0 inch water gauge (w.g.) level; however, the individual filters by specification are capable of sustaining up to 10 inches (w.g.) pressure differential without significant reduction in efficiency or structural damage. HEPA filters are generally used until pressure differentials as high as 5 inches are observed (3-2).

The principal air cleaning technologies employed at nuclear facilities for gaseous radionuclides, especially radioiodines, are organic and inorganic adsorption. Activated charcoal is the principal organic adsorbent employed for radioiodine removal. The activated charcoal is generally obtained from coconuts; however, wood, bituminous coal, petroleum, sludge, and nut shells are also employed. Activation is accomplished by controlled heating in a steam atmosphere to drive off organic matter and generate large internal surfaces on which the adsorption can take place (3-2). The internal surface areas of activated charcoal ranges from 700 to 1800 square meters per gram based on the nitrogen isotherm from the BET (Brunauner, Emmett, and Teller) method. Activated charcoal is often impregnated with triethylene diamine (TEDA), potassium iodide (KI), or iodine gas (I_2) to enhance the adsorption capability of the charcoal for organic radioiodine compounds. The efficiency of activated charcoal adsorbers is a function of granule size, gas residence time, the degree of activation, the moisture and ash content, the impurities, airflow velocity through the charcoal, and temperature and relative humidity. The efficiency of high quality charcoal adsorber beds is generally greater than 99% under most normal operating conditions. Design efficiencies for methyl iodide of a 2-inch bed of impregnated activated charcoal with 0.2 second gas residence time are given in Table 3-4 (3-2). These efficiencies are for single-pass use. Recirculatory systems would exhibit increased efficiencies.

Inorganic absorbents in use at existing nuclear facilities include molecular sieves and alumina traps. The most common molecular sieve in use today is the silver zeolite while alumina traps impregnated with silver oxide or silver nitrate are often employed for radioactive gas removal. The principal advantages of inorganic adsorbents, especially silver zeolite (AgX), are non-flammability, high-temperature retention of radioiodines, low explosion hazard when nitrogen oxides are contained in the off-gas stream, high efficiency under service conditions, and the relatively low solubility of the waste solids produced by iodine removal. The principal disadvantages are economic. A volume of silver impregnated molecular sieve costs 40 to 50 times the equivalent volume of activated charcoal (3-2). Efficiencies of silver zeolites are generally over 99% for radioiodines. Zeolite poisoning by cations has been observed in some systems over extended periods of use. The silver impregnated alumina traps, in general, do not exhibit good retention characteristics at high temperatures, high relative humidity, and high flow rates.

TABLE 3-4

Design Efficiency Values for Single-Pass Impregnated Activated Charcoal Filter*

	Methyl Iodide Removal Efficiency	
Relative Humidity	70°F	270°F
≤85	95	98
90	90	90
95	80	70
98	70	30

---

* Source : Ref 3-2; two-inch bed of impregnated activated charcoal with a 0.2 second gas residence time.

Uranium Conversion Plants

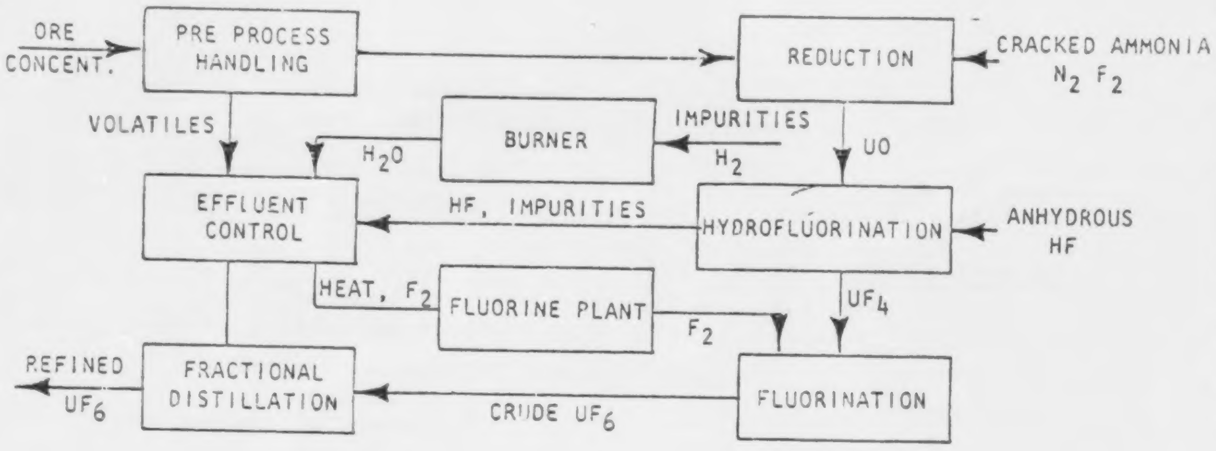
Processed uranium ore (about 0.714 atom percent ^{235}U) or reprocessed irradiated uranium (about 1 to 2 atom percent ^{235}U) must be enriched in its fissile isotope content prior to utilization as fuel in most of the currently operating and/or planned central station nuclear power plants. Prior to enrichment by gaseous diffusion process, which is the major current technology utilized for enrichment, the uranium must be converted to uranium hexafluoride (UF_6) which is a gaseous compound of uranium suitable for this process. This subsection considers the current airborne emission control technologies at these conversion plants.

Currently, there are only two commercial UF_6 production facilities in the United States, both licensed by the NRC in accordance with applicable sections of 10 CFR: the Kerr-McGee Sequoyah plant in eastern Oklahoma (3-3) and the Allied Chemical plant in Metropolis, Illinois (3-4). Both of these plants utilize processed uranium ore concentrate as the starting feed (3-6). The two plants have a combined annual production capacity of 17,300 metric tons of uranium as UF_6 (3-6). The Department of Energy also operates a UF_6 production plant located in Fernald, Ohio that refines uranium ore concentrate (3-7). Gaseous diffusion plants operated by the Department of Energy at Paducah, Kentucky, and Portsmouth, Ohio also produce UF_6 and utilize refined ore or non-commercial fuel reprocessing plant purified feed (3-7). A commercial production plant which can produce UF_6 from low-enriched uranium recovered from irradiated nuclear power reactor fuel elements has been constructed near Barnwell, South Carolina by Allied-General Nuclear Services (3-5). "Nuclear-grade" uranium dioxide, uranium metal, and uranium tetraflouride are other possible products of a uranium conversion plants. However, most uranium is converted to uranium hexaflouride.

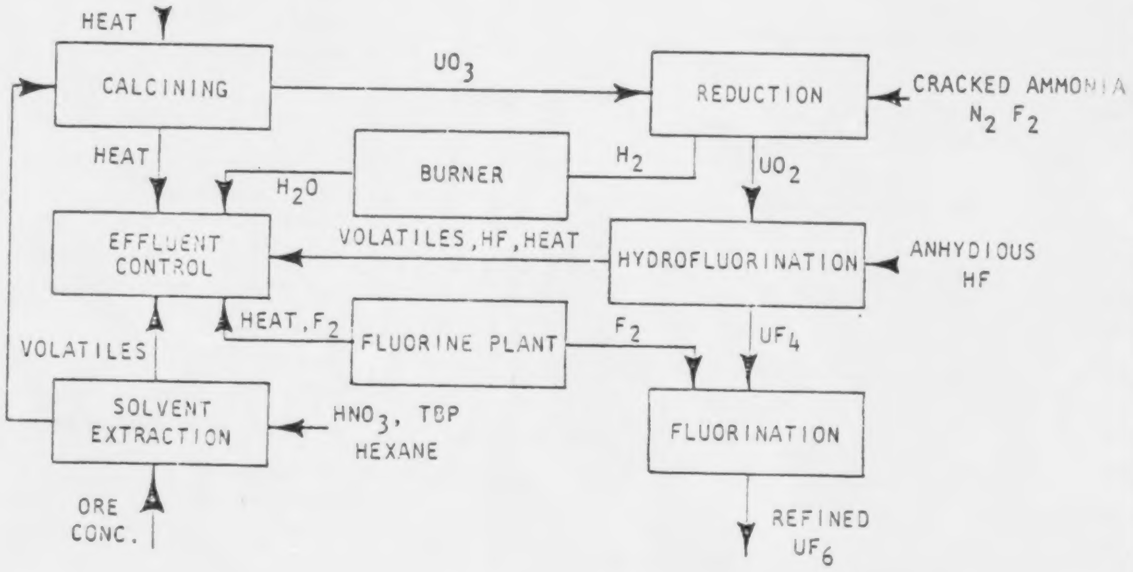
Two processes are presently utilized commercially for UF_6 production (3-6 through 3-8). The "dry process", also called the "fluorination-fractionation" process, is utilized in the Allied Chemical Metropolis plant. In this process, the uranium concentrate undergoes successive reduction, hydroflourination, and flourination steps in fluidized bed reactors, after which the crude UF_6 is purified by fractional distillation. The "wet process", also called the "solvent extraction-fluorination" process, is utilized in the Kerr-McGee Sequoyah plant. This process utilizes a chemical solvent extraction step to prepare a high purity uranium oxide prior to the reduction, hydroflourination, and flourination steps. The primary difference between the two processes is whether the uranium is purified by solvent extraction before conversion to UF_6 or by fractional distillation of the UF_6 after conversion. Another difference is that a flame reactor is utilized in the "wet process" to carry out the flourination of uranium tetraflouride (UF_4) to UF_6. A process similar to the "dry process" but with no fractionation step has been planned for the Allied-General Nuclear Services Barnwell plant (3-5). Summary block diagrams of these two processes are given in Figure 3.3 (3-8).

Although both UF_6 conversion processes deliver the same end product, waste effluents are somewhat different, with the "dry process" generating a larger quantity of solid radioactive wastes and the "wet process", a larger quantity of liquid radioactive wastes (3-6).

The control technologies currently employed at the Metropolis and Sequoyah facilities and those planned for the Barnwell facility for reduction of routine airborne radionuclide emissions are listed in Table 3-5. All of the controls proposed for the Barnwell, South Carolina plant are presently demonstrated control technologies. Particulate radionuclide releases are reduced through the use of dry collectors (bag-house filters, cyclones, porous carbon filters, and


ORE CONCENT.
PRE PROCESS HANDLING
REDUCTION
CRACKED AMMONIA N_2 F_2
VOLATILES
BURNER
IMPURITIES
H_2O
H_2
UO
EFFLUENT CONTROL
HF, IMPURITIES
HYDROFLUORINATION
ANHYDROUS HF
HEAT, F_2
FLUORINE PLANT
UF_4
F_2
REFINED UF_6
FRACTIONAL DISTILLATION
CRUDE UF_6
FLUORINATION

(A) DRY PROCESS


HEAT
CALCINING
UO_3
REDUCTION
CRACKED AMMONIA N_2 F_2
HEAT
BURNER
H_2
UO_2
H_2O
EFFLUENT CONTROL
VOLATILES,HF,HEAT
HYDROFLUORINATION
ANHYDIOUS HF
HEAT,F_2
FLUORINE PLANT
F_2
UF_4
VOLATILES
SOLVENT EXTRACTION
HNO_3, TBP HEXANE
FLUORINATION
ORE CONC.
REFINED UF_6

(B) WET PROCESS

UF6 CONVERSION METHODOLOGICS

DAMES & MOORE

FIGURE 3.3

TABLE 3-5

Summary of Control Technologies Employed at Commercial UF_6 Conversion Facilities

Stack No. and Identification	Contaminant Removed	Primary (1), Secondary (2) and Tertiary (3) Systems	Rated[a] Efficiency
Metropolis Plant (Dry Process)[b]			
1-1, 1-2, 1-3, 1-10, 1-11 1-12 Dust Collectors	Particulates	(1) MP Baghouse[c]	99.9
		(2) MP Baghouse	99.9
1-4, 1-7 Vacuum Cleaners	Particulates	(1) Spencer cyclone	95
		(2) MP Baghouse	95
		(3) Spencer Turbine Baghouse	99
1-12 Ash Vacuum Cleaner	Particulates	(1) Spencer Cyclone	80
		(2) MP Baghouse	99.9
		(3) Spencer Turbine Baghouse	99.9
1-5, 1-6 Reductor Filters	Particulates	(1) Porous metal filters	>99.9
		(2) Porous metal filters	>99.9
1-5, 1-6 Reductor Scrubbers	H_2S	(1) Spray tower	50
		(2) Venturi Jet	85
		(3) Packed Tower	99+
1-23, 1-24 Hydrofluorinator Filters	Particulates	(1) Two Porous carbon filters	>99.9
		(2) Two Porous carbon filters	>99.9
1-23, 1-24 Hydrofluorinator Scrubbers	HF	(1) Two Water Venturi Jets	88
		(2) Venturi Jet (KOH)	85
		(3) Packed Tower (KOH)	99+
1-13, 1-14 Fluorinator Filters	Particulates	(1) Two Porous metal filters	>99.9
		(2) Two Porous metal filters	>99.9
1-13, 1-14 Fluorinator Scrubbers	HF, F_2, UF_6	(1) Spray Tower	80
		(2) Packed Tower	99
		(3) Coke Box	99
3-2 Dust Collector	Particulates	(1) Wheelabrator Baghouse	99.9
4-2 Scrubber Vent	Particulates HF, SO_2	(1) MP Baghouse	99.9
		(2) Spray Tower	95
Sequoyah Plant (Wet Process)[d]			
Sampling Plant	Particulates	Baghouse filters	--
Denitrification, reduction, hydrofluorination, fluorination systems	Particulates HF	Baghouse filters plus Cold Traps plus Scrubber	--

(Continued)

TABLE 3-5(Continued)

Barnwell Plant (Wet Process)[e]

Stream Identification	System	Rated[a] Efficiency
Fluorinator Bed Recycle Handling System	Baghouse plus HEPA filters	— —[f]
Concentration and Calcining Condensate Receiver Vents	None	
Water vapor from UO_3 Drier	Two baghouse filters	—
Dust collector systems for UO_3 grinding, transport and sizing operations, and UF_4 conveying and fluorinator feeding operations	Two baghouse filters	—
Reductor Off-gas	Particulate filters	—[f]
Hydrofluorinator Off-gas	Particulate filters plus KOH Scrubber	—[f]
Fluorinator Off-Gas	Porous metal filters plus cold traps plus KOH spray tower	— 99.9 for UF_6 99.9 for UF_6
Dust collector system for the bed material handling operations	Two baghouse filters plus HEPA filters	-- —[f]
Off-gas from waste calciner, and uranium recovery calciner	Baghouse filter	--
Vent Stream from UF_6 product sampling system	Scrubber	—
Off-gas from scrap recovery	Dust collector plus baghouse	—
Off-gas from uranium recovery spent solutions evaporator	None	--

---

(a) It is not specified in the source document whether the rated efficiencies are number efficiencies or mass efficiencies.

(b) Source : Ref 3-4; Allied-Chemical Metropolis Plant; Operational, dry process with uranium ore concentrate feed (see Text).

(c) Micro-Pulsaire Baghouse filter.

(d) Source : Ref 3-3; Kerr McGee Sequoyah Plant, Operational, wet process with uranium ore concentrate feed (see Text).

(e) Source : Ref 3-5, Allied-General Nuclear Services, Barnwell Plant, preoperational design similar to dry process with no fractionation step.

(f) Particulate filter systems contain HEPA filters, see "Background" subsection for HEPA efficiencies.

porous metal filters) and wet collectors (spray towers, packed towers, wet and venturi scrubbers). Gaseous radionuclides are removed from gaseous effluents by spray towers, packed towers, venturi scrubbers and coke boxes.

In both the "dry" and the "wet" process, small quantities of the uranium isotopes and their progeny are released in airborne effluents. Routine stack emissions from the Metropolis facility consist primarily of insoluble uranium compounds (processed ore concentrates, and UF_4) (3-4). Soluble uranyl flouride (UO_2F_2) formed by UF_6 decomposition is emitted in stack releases from the flourination and distillation sections (3-5). Small quantities of UO_2F_2 are routinely released from the Sequoyah facility. Additionally, small quantities of other uranium compounds such as UO_3, UO_2, and UF_4 are occasionally released as a result of entrainment in air streams from leaky packaging glands, spillage during handling and leakage through particulate filters utilized in solids transfer and vacuum cleaning systems (3-3).

Laboratory and on-line plant experience have demonstrated that the reverse-jet type bag-house filter is 99.9% efficient under typical industrial conditions. Leaks around seals and bag holes are the primary mechanisms for efficiency drops. An average efficiency of 99.986% was obtained for a blow ring type bag-house filter under no leak conditions (3-7).

A cyclone with a rated efficiency of 95% is used as a primary control for particulate radionuclide releases from certain systems at the Metropolis facility (3-4). Porous metal filters are also utilized in the Metropolis facility and are planned for use at the Barnwell plant. Porous metal filters are fabricated by sintering pre-alloyed metal powders of selected particle sizes in a controlled atmosphere furnace such that up to 50% of the volume of the metal filter consists of interconnecting voids or pores (3-7). In porous metal filters, the particulates can impinge on the filter surfaces which provides removal in addition to filtration based on the mean pore diameter. Through this mechanism, a 1/8 inch thick filter with a mean pore size of 10 microns will remove 98% of the 0.7 micron diameter particles (3-7). The porous metal filters employed at the Metropolis plant each have rated efficiencies of greater than 99.9% (3-4). The use of HEPA filters is planned for the Barnwell plant. Table 3-6 lists wet dust collector efficiencies.

The efficiencies of various noxious gas wet scrubbers are listed in Table 3-7. Physical and chemical processes are used for gas removal in these scrubbers. The KOH in KOH scrubbers will react with gaseous UF_6 to form solid $K_2U_2O_7$ which is removed from the air stream. Wet scrubbers can be found in primary, secondary, and tertiary gas treatment systems of the three plants examined.

A study of the gaseous and airborne radioactive waste treatment variables was performed for a hypothetical 10,000 metric ton per year "dry process" UF_6 conversion plant (3-7). A description of four model cases employing differing treatments of exhaust gases for airborne radionuclide reduction is provided in Table 3-8 for this model plant. The base case costs (Case 1) are not specified in (3-7). The capital costs, annual fixed charges, annual operating costs, and the total annual costs in addition to the base case costs, are listed in Table 3-9. These costs are in 1978 dollars and were obtained from the 1977 dollars given in (3-7) by multiplying with a factor of 1.076 based upon the Consumer Price Index listing.

TABLE 3-6

Efficiency of Wet Dust Collectors*

Type of Dust Collector	Average Pressure Drop (in H_2O)	Efficiency (%) for		
		5µm Dust	2µm Dust	1µm Dust
Baffle (Orifice)	6.1	93	75	40
Spray Tower	1.4	94	87	55
Packed Tower (Fluidized bed)	2.4	95		58
Wet impingement	6.1	97	95	80
Venturi				
Medium Energy	20.0	99.8	99	97
High Energy	31.5	99.9		98

---

* Source: Ref 3-6. The references given in (3-6) are:
C.J. Stairmand, "Removal of Dust from Gases", pp. 364-402 in Processes for Air Pollution Control, 2nd ed., The Chemical Rubber Company, Cleveland, Ohio, 1972
C.J. Stairmand, The Chemical Engineer Vol.194, pp.310-26 (December, 1965)

TABLE 3-7*

Efficiency of Noxious Gas Absorbers

Type of Gas Absorber	Gas Absorbed	Srubbing Medium	Efficiency (%)
Baffle (Orifice) with Condenser	Denitrator off-gas	40% HNO_3	70[a]
Spray Tower	H_2S-S	Water	50[b]
	UF_6	KOH	80[b]
	HF	KOH	80[c,d]
	F_2	KOH	80[c,d]
Wetted Packed Tower	UF_6	KOH	99[b]
	HF	KOH	99[c,d]
	F_2	KOH	99[c,d]
Medium-Energy Venturi	HF	Water	90[b]
High-Energy Venturi	HF	Water	95[e]
	HNO_3	Water	97[e]
	NO_2	Water	30[e]
	HF	KOH	99[f]
	H_2S	KOH	85[b,e]
	SO_2	KOH	98[e]
KOH Coke Box	UF_6		90[g,h]
	HF		90[g,h]
	F_2		90[g,h]
NO_x Absorber Tower (20-Plate Bubble Tower)	NO_x	Water	95[i]

---

[a] Kerr-McGee Corporation, Applicants Environmental Report Sequoyah Uranium Hexafluoride Production Plant, Docket 40-8027 (June 1972, pp. 40-51

[b] A.D. Riley (Manager, Allied Chemical UF_6 plant), J.H. Thomas (Technical Superintendent), and R.W. Yates (Health Physicist), personal communication to M.B. Sears, November 13, 1974.

[c] By analogy to UF_6.

[d] By analogy to HCl. (S.K. Kempner, E.N. Seiler, & D.H. Bowman, J. Air Pollution Control Association 20(3), 139-43 (1970).

[e] L.S. Harris, Chem. Eng. Progr. 62(4), 55-59 (April 1966)

[f] By analogy to caustic scrubbing of Cl_2 (footnote e)

[g] Efficiency when used as tertiary scrubber in a train.

[h] Downgraded efficiency of proprietary technology from 99.9% (footnote b) to 90% because it is not in the public domain

[i] B.J.Mayland and R.C.Heinze, Chem.Eng.Progr. 69(5), 75-76 (May 1973)

---

* Source : Ref 3-6.

TABLE 3-8

Summary of Gaseous and Airborne Radwaste Treatment
Variables for the Model 10,000 metric-ton/year
Dry Process UF_6 Conversion Plant*

Case and Objective	Treatment
Case 1 Base case; control uranium losses and release of radium and noxious gases	Primary bag filters on dust-bearing air from materials handling processes; primary and secondary filters on chemical reactors; primary and secondary scrubbers H_2S-bearing effluents.
Case 2 Reduce uranium and radium release by 2.5; reduce HF release by 70.	Same as Case 1 plus secondary bag filters; tertiary scrubbers on HF-bearing effluents; burn sulfide to SO_2 and release.
Case 3 Reduce uranium and radium releases in building ventilation effluent by 14.	Same as Case 2 plus water baffle scrubbers on building ventilation effluent; exclude ammonium and sodium salts from the feed.
Case 4 Reduce uranium and radium releases by 3000; reduce HF by 700; reduce SO_2 release by 50 compared with Cases 2&3.	Same as Case 3 plus HEPA filters on process effluents; more efficient HF condensers; F_2 cleanup reactor; UF_6 cleanup reactor; SO_3 scrubber.

---

* Source : Ref 3-7.

TABLE 3-9

Estimated Capital and Annual Costs (1978 dollars)
in Addition to the Base Case (Case 1) for the 10,000
metric-ton/year Model Dry Process UF_6 Conversion Plant*

	Radwaste Case	Capital Cost(a)	Annual Fixed Charge	Annual Operating Cost	Total Annual Cost
Building	2	NA	NA	NA	NA
Ventilation	3	2000(b)	519	85	604
($1000)	4	6702(b)	1742	364	2106
Dust Control	2	1273	331	38	369
($1000)	3	1273	331	38	369
	4	1602	417	52	469
Process	2	145(c)	38	18	56
Off-Gas	3	192	50	23	73
($1000)	4	695(d)	181	80	261

(a) Includes direct cost (installed equipment but not structure cost) and indirect cost. The interest during construction is included as an indirect cost.

(b) Includes a capital cost credit of $178,100 (1973 dollars) for Case 1 building exhaust fans.

(c) Includes a capital cost credit of $74,500 (1973 dollars) for replacement of Case 1 reduction off-gas equipment.

(d) Includes a capital cost credit of $146,300 (1973 dollars) for replacement of Case 1 reduction, hydroflourination, and flourination and flourine cell off-gas equipment.

---

* Source : Ref 3-7; 1978 dollars obtained from 1973 dollars given in (3-7) by multiplying with a factor of 1.467 based upon the Consumer Price Index listing; "Base Case" costs are not given in (3-7).

Gaseous Diffusion (Enrichment) Plants

Most of the central station nuclear power plants in the U.S. are "thermal" reactors, i.e., they utilize primarily low energy (thermal) neutrons to sustain the chain reaction. This process requires uranium fuel enriched in fissile uranium-235 content which can be fissioned by low energy neutrons. The mined uranium ore consists of about 99.3 atom percent of fissionable uranium-238. Currently, the only process being used in the United States to produce commercial quantities of enriched uranium is based on the gaseous diffusion technology. This process utilizes the slight difference in average velocities of gas molecules arising from the fractional mass difference between the two isotopes at a given temperature. Uranium enrichment for central station nuclear power plant fuels in the United States is currently carried out at three gaseous diffusion plants at Oak Ridge, Tennessee, Paducah, Kentucky and Portsmouth, Ohio; all are owned and operated by the Department of Energy.

At an enrichment plant, solid UF_6 contained in 10 and 14 ton cylinders is vaporized by heating with steam and fed to a diffusion cascade. Each stage of the cascade produces fractionally enriched uranium. The maximum theoretical enrichment in the isotopic content for a single stage is a factor of 1.0043 (3-6). Enrichment of uranium ore to about 4% ^{235}U requires about 1200 stages, and attainment of enrichments exceeding 90% requires more than 3000 stages. The enriched material flows upward until it reaches the desired enrichment level where it is compressed, condensed to liquid form, and packaged into a product cylinder. The depleted stream flows downward until it is removed as tails, which also is compressed, condensed and packaged. The tails assay at which an enrichment plant is operated is based on a balance of a number of factors that include the availability of uranium feed, the enrichment plant capacity, and electrical power availability (3-6).

Light gases such as nitrogen from equipment purges, air inleakage, coolant vapors from coolant system leaks, and hydrofluoric acid from the hydrolysis of UF_6 are also processed in the diffusion cascade. Removal of the undesired light gases before the product withdrawal point is accomplished by a purge cascade. The light gases are passed through an alumina trap before stack discharge.

The cleaning and repair of process equipment constitutes another major portion of the operations at a gaseous diffusion plant. Prior to repair, equipment is transferred to a decontamination facility where it is rinsed with dilute nitric acid or ammonium carbonate and is sometimes rubbed with abrasive tools. The cleaning solutions are transferred to nuclearly-safe tanks from which they are conveyed back to the uranium recovery operation.

Oak Ridge Gaseous Diffusion Plant (ORGDP)

The Oak Ridge Gaseous Diffusion Plant (3-9) is located within the Oak Ridge National Laboratory and includes the first large-scale gaseous diffusion plant (K-25) which yielded its first delivered product in March of 1945. The ORGDP presently consists of five diffusion buildings (K-25, K-27, K-29, K-31, and K-33) where a total of 5104 separative stages are housed. This facility is capable of performing 4.7 million separative work units (SWU) per year. The dry air system at the ORGDP has a maximum capacity of 22,000 scfm. The nitrogen purge plant operates at a maximum 180 scfm level.

The gaseous effluent system at ORGDP consists of a primary KOH scrubber with a alumina (Al_2O_3) trap system (3-12). During normal operations the KOH scrubber is the main control technology employed with the alumina trap serving as "backup" system. The KOH scrubber slurry is passed through a nuclearly-safe U-shaped storage tank, filtered and recycled back to the scrubber. Upon KOH depletion, the scrubber stream is withdrawn and reacted with calcium hydroxide

(CaOH) to yield KOH plus CaF_2 precipitate. The precipitate is removed from the system by a rotary drum filter and the freshened KOH is returned to the scrubber storage tank. The scrubber efficiency at the ORGDP is on the order of 99% (3-12). The KOH scrubber produces a significant (unspecified) amount of sludge each year. Air flow is controlled by pressure zonation at the ORDGP, and the building ventilation system utilizes HEPA filtration.

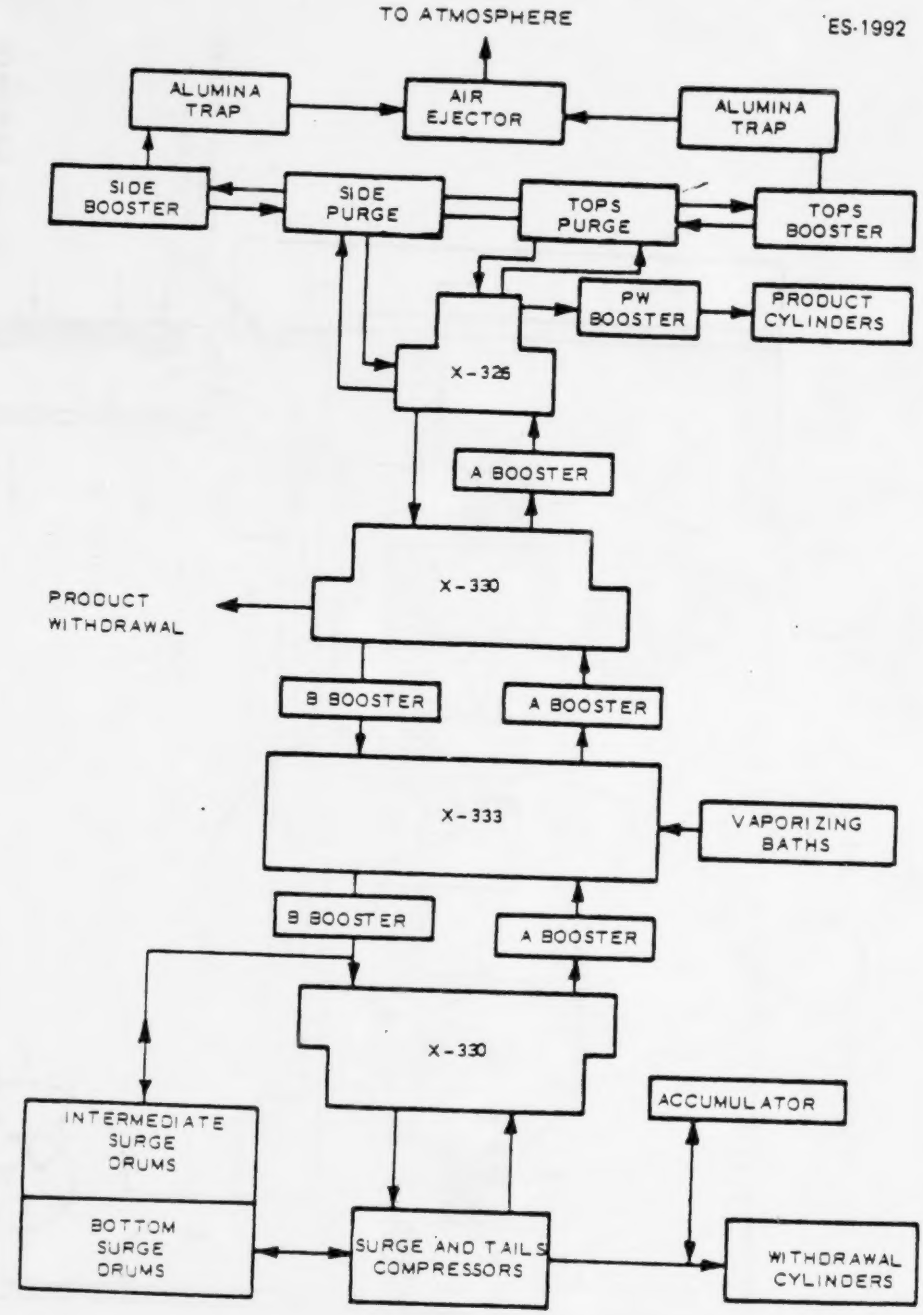
Portsmouth Gaseous Diffusion Plant - Portsmouth, Ohio

The Portsmouth Gaseous Diffusion Plant (3-10) presently consists of three cascade buildings with a total capacity of 4080 separative stages. Plant process gas flow is illustrated in Figure 3.4.

This facility is capable of performing 5.2 million SWU/year (3-11). The dry air system at the plant has a maximum capacity of 22,000 scfm while the nitrogen purge plant operates at a maximum 65 scfm level. A typical heating and ventilating system utilized at this plant is illustrated in Figure 3.5.

At Portsmouth Plant, two purge cascades are used to remove light contaminants in the gaseous stream. After leaving the cascades, the gaseous stream is passed through an alumina (Al_2O_3) trap. The annual residuals from this process total about 700 lbs per year (3-10). The gaseous effluents from the purge cascade are listed below:

Radionuclide	Ci/yr
^{99}Tc	5.83
^{234}Th	$2.78x10^{-2}$
^{234m}Pa	$2.78x10^{-2}$
^{234}U	$5.31x10^{-2}$
^{235}U	$2.17x10^{-3}$
^{236}U	$8.22x10^{-5}$
^{238}U	$9.15x10^{-5}$

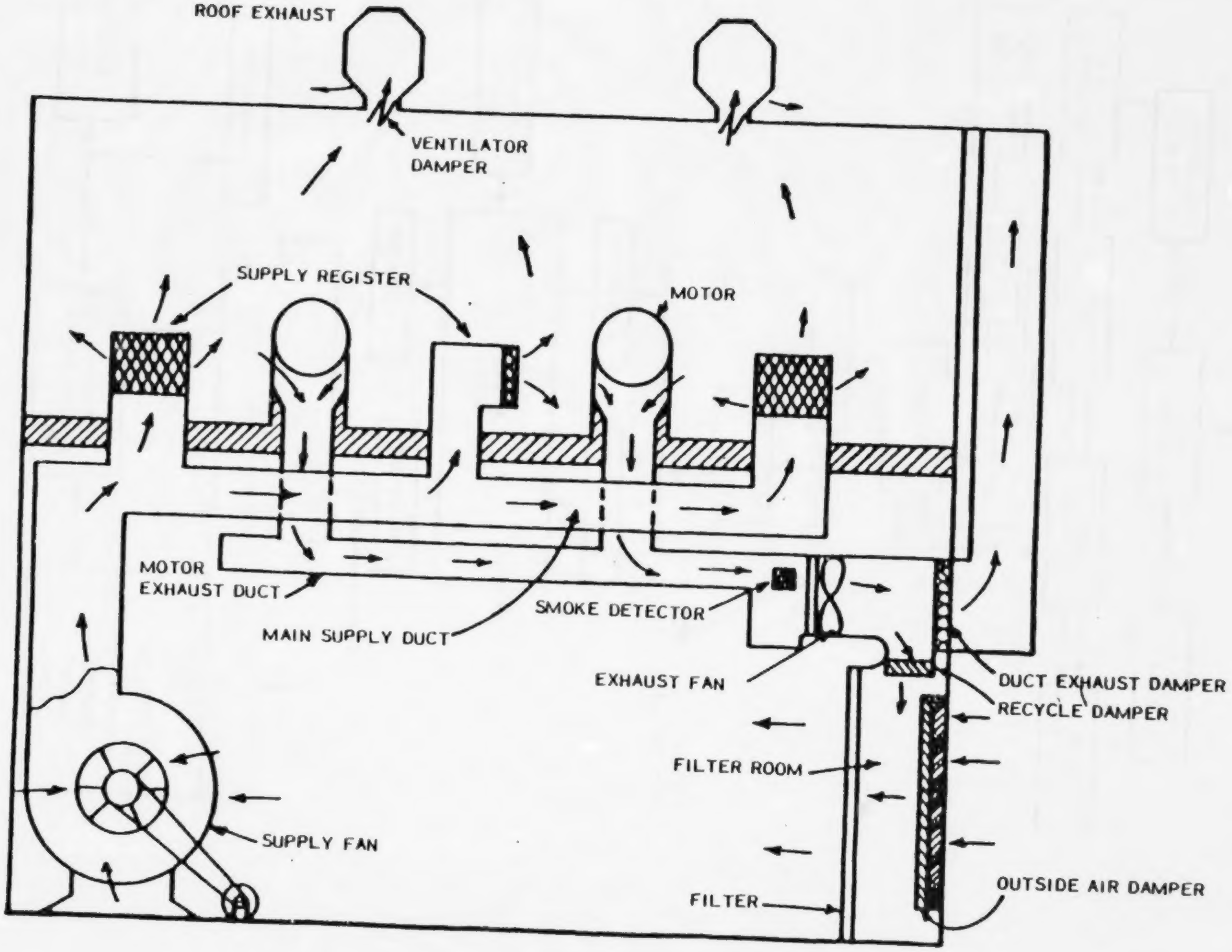

TO ATMOSPHERE
ES-1992
ALUMINA TRAP
AIR EJECTOR
ALUMINA TRAP
SIDE BOOSTER
SIDE PURGE
TOPS PURGE
TOPS BOOSTER
PW BOOSTER
PRODUCT CYLINDERS
X-326
A BOOSTER
X-330
PRODUCT WITHDRAWAL
B BOOSTER
A BOOSTER
X-333
VAPORIZING BATHS
B BOOSTER
A BOOSTER
X-330
ACCUMULATOR
INTERMEDIATE SURGE DRUMS
BOTTOM SURGE DRUMS
SURGE AND TAILS COMPRESSORS
WITHDRAWAL CYLINDERS

PLANT PROCESS GAS FLOW

Source: Reference 3-10

DAMES & MOORE

FIGURE 3.4


ROOF EXHAUST
VENTILATOR DAMPER
SUPPLY REGISTER
MOTOR
MOTOR EXHAUST DUCT
MAIN SUPPLY DUCT
SMOKE DETECTOR
EXHAUST FAN
DUCT EXHAUST DAMPER
RECYCLE DAMPER
FILTER ROOM
SUPPLY FAN
FILTER
OUTSIDE AIR DAMPER

TYPICAL HEATING AND VENTILATING SYSTEM

Source: Reference 3-10

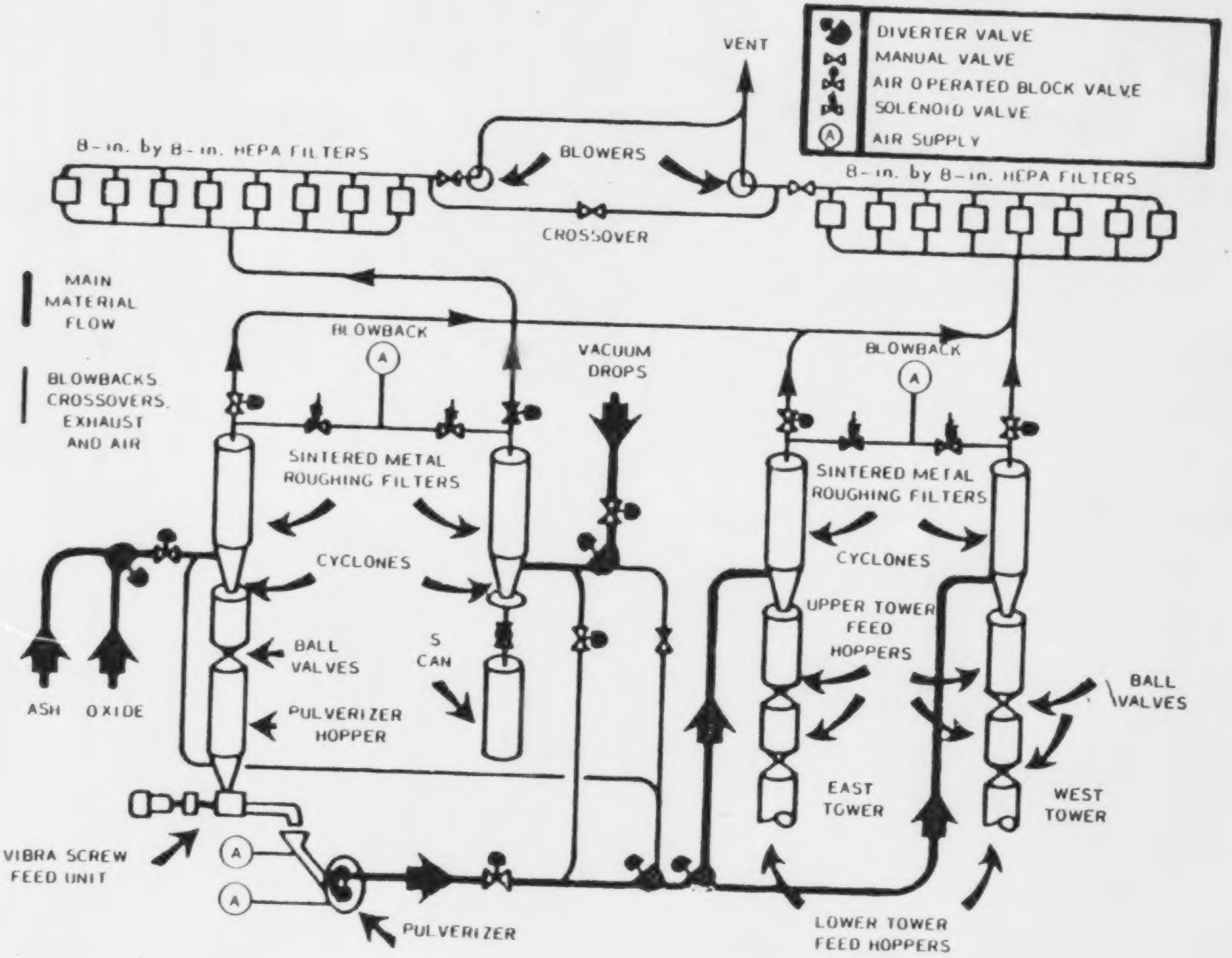
DAMES & MOORE

FIGURE 3.5

The decontamination and recovery facility is the other principal source of radioactive airborne emissions at the Portsmouth Plant. The cleaning air used to vacuum disassembled parts is filtered with a HEPA filter before exhausting to the atmosphere. The control devices on the incinerator used to burn combustible contaminated material are not known. The incinerator is in operation an average of 540 hours per year and a particulate uranium emission rate of 6 to 15 ug/hr is reported (3-10).

The U_3O_8 to UF_6 conversion system at the plant utilizes a pneumatic system which is illustrated in Figure 3.6. The pneumatic system is used for solids transfer and contains control devices to reduce particulate emissions. Several different functions of the pneumatic system are: unloading U_3O_8 to the pulverized feed hopper, transferring ash from the bottom of the flame tower to the pulverized feed hopper, grinding and transfering material from the pulverizer feed hopper to the tower feed hopper, grinding and transferring material in the pulverized feed hopper to a can for removal from the system, and serving as a vacuum cleaning system thoughout the area (3-10). The pneumatic system is driven by a 265 cfm blower and immediately upstream of the blower is a bank of eight, 8 by 8 inch HEPA filters. All material delivery points are equipped with a cyclone and sintered metal roughing filter. All components of the pneumatic system have nuclearly safe geometries (3-10).

Certain parts of the facility, where release of solid uranium compounds could be expected, are enclosed in glove boxes. Oxide unloading booth, can loading booth, pulverizer compartment, upper tower section including the feed screw and the disperser assembly, and lower tower section including the ash pot and the process gas filters are all enclosed in glove boxes constructed of stainless steel framing with plexiglass panels. All glove box effluents pass through stainless steel roughing filters and HEPA filters.


DIVERTER VALVE
MANUAL VALVE
AIR OPERATED BLOCK VALVE
SOLENOID VALVE
AIR SUPPLY
VENT
BLOWERS
8-in. by 8-in. HEPA FILTERS
8-in. by 8-in. HEPA FILTERS
CROSSOVER
MAIN MATERIAL FLOW
BLOWBACKS CROSSOVERS, EXHAUST AND AIR
BLOWBACK
BLOWBACK
VACUUM DROPS
SINTERED METAL ROUGHING FILTERS
SINTERED METAL ROUGHING FILTERS
CYCLONES
CYCLONES
BALL VALVES
S CAN
PULVERIZER HOPPER
ASH
OXIDE
UPPER TOWER FEED HOPPERS
BALL VALVES
EAST TOWER
WEST TOWER
VIBRA SCREW FEED UNIT
PULVERIZER
LOWER TOWER FEED HOPPERS
A

PNEUMATIC SYSTEM

Source: Reference 3-10

DAMES & MOORE

FIGURE 3.6

Airborne effluents from the decontamination facility include 17 g/year of uranium from the oxide conversion area and 8 mg/year of uranium from the incinerator (3-10).

Paducah Gaseous Diffusion Plant - Paducah, Kentucky

The Paducah Gaseous Diffusion Plant (3-9) presently consists of five cascade buildings with a total of 1812 separative stages. This facility is capable of performing 7.3 million SWU/year. The dry air system of the plant has a maximum of 15,000 scfm while the nitrogen purge plant operates at a maximum of 195 scfm level. Specific information on radioactive airborne emission control technology was not available. It is assumed that the systems are similar to those employed at ORGDP and Portsmouth.

Fuel Fabrication Facilities

The final step in the front end of the nuclear fuel cycle before the fuel is utilized in central station nuclear power plants is fuel fabrication. Currently, there are two major types of fuel fabrication facilities: those that produce fuel for light water reactors (LWRs), and facilities that produce fuel for other types of reactors such as the high temperature gas-cooled reactors (HTGR), breeder reactors, and research reactors. The facilities in existence are detailed in Tables 3-10 and 3-11.

A description of the process for LWR fuel fabrication plants is given below, followed by a plant by plant description of the control technology and other relevant data. Also included are the planned processes and control technologies for the mixed oxide fuel fabrication plants for LWRs. The process descriptions of plants generating fuel for reactors other than LWRs could not be obtained in sufficient detail for inclusion. However, the control technologies and other relevant data for the "non-LWR" fuel fabrication plants are discussed for several cases.

LWR Fuel Fabrication Plants

Fuel fabrication for LWRs includes the conversion of uranium hexafluoride (UF_6) into uranium oxide (UO_2) powder, pelletization of the powder, sintering of the pellets for densification, loading of the pellets into stainless steel or zircaloy tubes, welding of these fuel rods for closure, and finally arrangement of the rods into fixed arrays as fuel elements or assemblies. In the case of mixed oxide fuels (i.e., containing plutonium as PuO_2), which are currently not utilized in LWRs, the fabrication includes the conversion of plutonium nitrate to an oxide and the weighing and mixing of the heavy metal oxides in the desired blend.

TABLE 3-10

LWR Fuel Fabrication Plants

Licensee	Plant Location	Plant Feed Material	Plant Products
Babcock & Wilcox	Apollo, Pa.	UF_6	UO_2 Powder or Pellets
Babcock & Wilcox	Lynchburg, Va.	UO_2 Pellets	Fuel Assemblies
Combustion Engineering	Hematite, Mo.	UF_6	UO_2 Powder or Pellets
Combustion Engineering	Windsor, Conn.	UO_2 Powder	Fuel Assemblies
Exxon Nuclear	Richland, Wash.	UF_6	Fuel Assemblies
General Electric	Wilmington, N.C.	UF_6	Fuel Assemblies
Kerr-McGee	Cimarron, Okla.	UF_6	UO_2 Powder or Pellets
Nuclear Fuel Services	Erwin, Tenn.	UF_6	UO_2 Powder or Pellets
Westinghouse	Columbia, S.C.	UF_6	Fuel Assemblies

Source : Ref 3-8, and Minerals Yearbook, U.S. Department of the Interior, (1975).

TABLE 3-11

Other Fuel Fabrication Plants

Licensee	Plant Location	Plant Products
Babcock & Wilcox	Leechburg, Pa.	Carbide, special, ^{233}U, and Pu fuels; Pu scrap; depleted U metal.
Battelle- Pacific Northwest Laboratories	Richland, Wash.	Pu fuels
General Atomic Co.	San Diego, Ca.	Carbide and special fuels
General Electric Co.	Vallecitos, Ca.	Pu fuels; U and Pu scrap.
North American Rockwell Corp.	Canoga Park, Ca.	Carbide, special, and Pu fuels; depleted U compounds and metal; Pu scrap
Texas Instruments, Inc.	Attleboro, Mass.	Special fuels
United States Nuclear	Oak Ridge, Tenn.	Special fuels
Westinghouse Electric Corp.	Cheswick, Pa.	Carbide and Pu fuels; Pu scrap
Whittaker Corp.	West Concord, Mass.	Special fuels; depleted U metal.

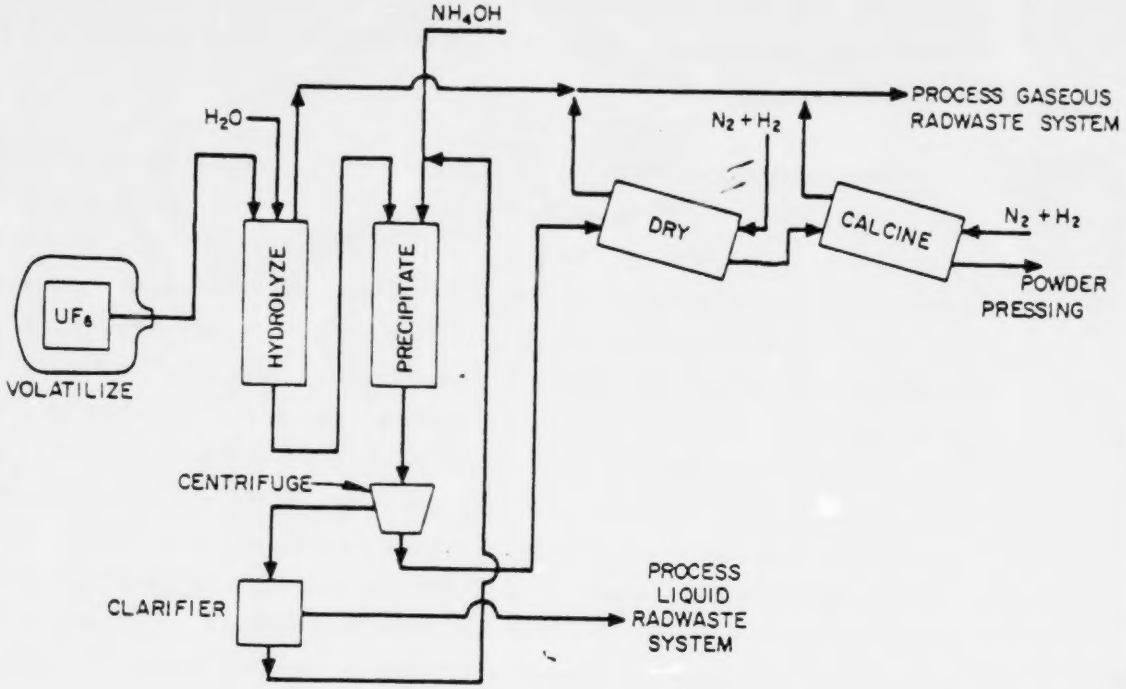
Source : Ref 3-25: Minerals Yearbook, U.S. Department of the Interior, (1975).

The two principal processes employed in the LWR fuel fabrication industry are the ammonium diuranate (ADU) process and the direct conversion (DC) process which are illustrated in Figures 3.7 and 3.8, respectively.

In the ADU process, UF_6 is received at the plant as a solid in pressurized 25 ft^3 shipping vessels. This vessel is fitted into a sealed system where UF_6 is vaporized, transferred to reaction chambers, hydrolyzed with water and neutralized with ammonium hydroxide to form a slurry of ammonium diuranate in an aqueous mixture of ammonium hydroxide and ammonium fluoride. The ammonium diuranate in the slurry is separated by centrifugation, dried and calcined to form the desired UO_2 powder. The product powder is pelletized, sintered, and emplaced into Zircaloy or stainless steel tubes. The ADU process generally includes a UO_2 recycle system to collect and reuse below-specification end products (e.g., cracked pellets) and a scrap recovery system to recover the uranium from incinerator ashes and floor sweepings. The gaseous process effluents in the ADU plant are scrubbed with a wet scrubber before release to the atmosphere.

In the DC process, the 25 ft^3 shipping vessels of solid UF_6 are emplaced in steam-heated containers to vaporize the solid. The gaseous UF_6 is introduced into a fluidized bed seeded with UO_2F_2 particles where it reacts with the fluidizing steam on the surface of the seed particles to produce UO_2F_2. After weighing, these particles are fed to in-series fluidized beds and converted to UO_2 and hydrofluoric acid (HF) using cracked ammonia and steam as the fluidizing reactants. The gaseous effluent from each fluidized bed flows through a sintered nickel filter for particulate removal prior to hydrofluoric acid removal by the gaseous effluent treatment system.

The radioactive components of the gaseous effluent at a typical uranium oxide fuel fabrication plant contains 0.04 wt % ^{234}U, 4.0 wt % ^{235}U, 0.20 wt % ^{236}U, and 95.76 wt % ^{238}U (3-13). The principal

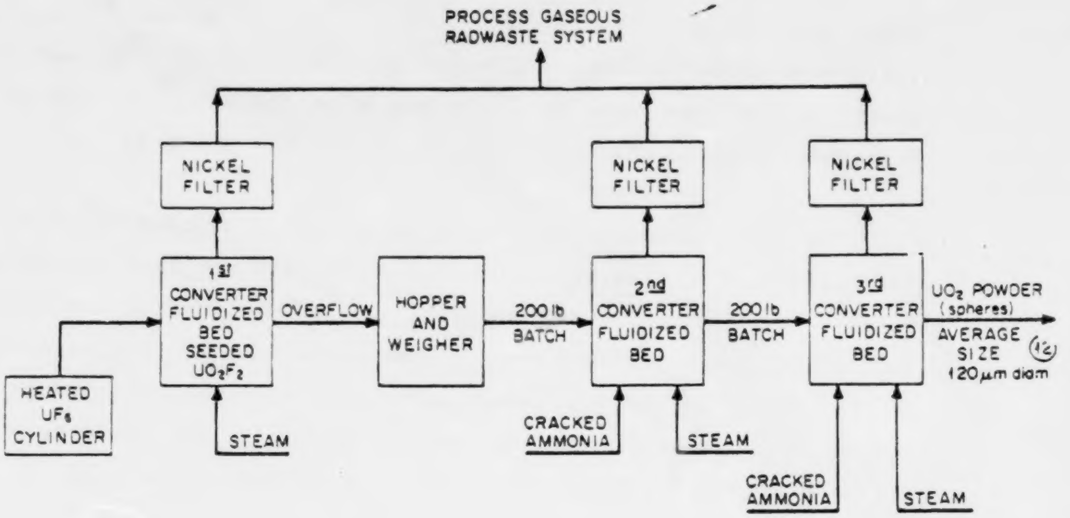

NH₄OH
H₂O
PROCESS GASEOUS RADWASTE SYSTEM
N₂ + H₂
DRY
CALCINE
N₂ + H₂
POWDER PRESSING
UF₆
HYDROLYZE
PRECIPITATE
VOLATILIZE
CENTRIFUGE
CLARIFIER
PROCESS LIQUID RADWASTE SYSTEM

NOMINAL ADU PROCESS SYSTEM
5 MTU/DAY

Source: Reference 3-13

DAMES & MOORE

FIGURE 3.7


PROCESS GASEOUS RADWASTE SYSTEM
NICKEL FILTER
NICKEL FILTER
NICKEL FILTER
1st CONVERTER FLUIDIZED BED SEEDED UO_2F_2
OVERFLOW
HOPPER AND WEIGHER
200 lb BATCH
2nd CONVERTER FLUIDIZED BED
200 lb BATCH
3rd CONVERTER FLUIDIZED BED
UO_2 POWDER (spheres)
AVERAGE SIZE ⑫
120 μm diam
HEATED UF_6 CYLINDER
STEAM
CRACKED AMMONIA
STEAM
CRACKED AMMONIA
STEAM

NOMINAL DC PROCESS SYSTEM
5 MTU/DAY

Source: Reference 3-13

DAMES & MOORE

FIGURE 3.8

radioactive daughters of concern include ^{234}Th and ^{234}Pr from the ^{238}U decay chain, and ^{231}Th from the ^{235}U decay chain (3-13).

For mixed oxide fuel fabrication plants, the fuel will contain up to 4.2 wt % ^{239}PuO$_2$. The feed at a mixed oxide plant will include small amounts of ^{238}Pu, ^{241}Am, ^{241}Pu, ^{237}U, ^{237}Np and ^{240}Pu. Very small quantities of fission products such as ^{106}Ru and ^{95}Zr and transplutonium isotopes such as ^{244}Cm may also follow ^{239}Pu through the reprocessing plant and be introduced in the feed material.

The airborne emission control technology and other relevant data for several of the existing LWR fuel fabrication plants are detailed below. Capital costs for installation of the control technologies and annual operating costs could not be obtained. A discussion of capital costs for HEPA filter systems are provided in Appendix IIA. System specific efficiencies, annual residuals and airborne radioactive effluents of the facilities are given where available.

Babcock & Wilcox - Apollo, Pennsylvania (Ref 3-15)
This plant was formerly operated by Nuclear Materials and Equipment Corporation (NUMEC). Air flow through the plant is controlled by pressure zonation. The exhaust flow rate is approximately 10,000 cfm. Outside air is introduced through "dust-stop" type filters. All process and ventilation air is vented to the atmosphere through a bank of 12 HEPA filters each with a throughput rating of 1000 cfm.

Babcock & Wilcox - Lynchburg, Virginia (Ref 3-16)
Air flow through the plant is controlled by pressure zonation. All process gas and ventilation gas systems are equipped with pre-filters and HEPA filters. The exhaust velocity for each work area varies according to the nature of the activity performed in each area. The velocities range from 100 fpm for open faced hoods to several thousand fpm for elephant trunk type pickups. All exhaust systems are vented near the roof.

Combustion Engineering - Windsor, Connecticut (Ref 3-17)

Air flow through the plant is controlled by pressure zonation. Flow volumes could not be obtained. Pre-filters and HEPA filters are installed into each local exhaust system. The exhaust velocities for low to moderate toxicity material fume hoods average 100 fpm with a minimum of 80 fpm. High toxicity fume hoods have an average face velocity of 125-200 fpm with a minimum of 125 fpm. Air velocities for general exhaust ducts range from 1200 to 2000 fpm for gases and 3000 to 5000 fpm for particulates.

Combustion Engineering - Hematite, Missouri (Ref 3-18)

This plant was formerly operated by Gulf-United Nuclear Fuels Corporation. The facility was opened in 1956 by Mallinkrodt Chemical Works for high and low enriched uranium fuel fabrication. Naval reactor fuel production capability was added in 1963. In 1971, Gulf-United Nuclear purchased the plant. Conversion from high- and low-enriched fuels to only low-enriched fuels was accomplished during 1974 when Combustion Engineering obtained the facility. This plant employs the DC process. Air flow through the plant is controlled by pressure zonation. Process offgases from the oxide building flow through two sets of sintered-metal filters and then passed through dry scrubbers. The dry scrubbers are crushed limestone towers which react with HF to produce CaF_2. Ventilation air from the oxide building is passed through HEPA filters. Process gaseous streams in the Pellet Plant are exhausted through two manifold systems each equipped with two banks of pre-filters and HEPA filters. All final filters are equipped with pressure differential monitors to detect excessive filter loading. In the building where cylinder heel washing, oxidation-reduction and pyrohydrolysis processing of recycle material occurs, process offgas from the cylinder heel operation is exhausted through a single HEPA filter, and the process offgas from the oxidation-reduction and pyrohydrolysis cells are passed through a KOH wet scrubber and then through a HEPA filter. All stacks are equipped with one or two HEPA filters.

Exxon Nuclear - Richland, Washington (Ref 3-19)

Air flow through the plant is controlled by pressure zonation. Exhaust air from the UO_2 building, either diverted from the recirculating system or from the once through ventilation system, is passed through two stages of HEPA filters. All gaseous streams containing corrosive fumes are wet scrubbed before being introduced into the first stage of the HEPA filtration. All second stage HEPA filters are equipped with a continuous pressure monitor. All HEPA filters meet or exceed specifications stated in military specification MIL-F-51079. All final filters have 99.95% efficiency for 0.8 micron particles.

General Electric - Wilmington, N.C. (Ref 3-20)

Air flow through the plant is controlled by pressure zonation. All process gaseous effluents are routed through HEPA filters. The UF_6-UO_2 conversion area has an exhaust rate of 34,350 cfm, a recirculation rate of 90,000 cfm, and 16 air changes per hour, exhaust air is scrubbed, then dried by steam heaters. The vaporization area has an exhaust rate of 6,000 cfm, a recirculation rate of 9,000 cfm, and 12.7 air changes per hour; exhaust air is scrubbed. The sintering area has an exhaust rate of 12,000 cfm, a recirculation rate of 60,000 cfm, and 27 air changes per hour. The UO_2 powder storage area has an exhaust rate of 5,000 cfm, a recirculation rate of 7,000 cfm, and 9.2 air changes per hour.

Kerr-McGee - Cimarron, Oklahoma (Ref 3-21)

Air flow through the plant is controlled by pressure zonation. The ventilation system for this fabrication plant consists of six air-handling units each with a 20,000 cfm capacity. This system distributes filtered air throughout all areas. The process and ventilation gaseous streams are vented through four 1000 cfm exhaust ducts. All air from processing and handling equipment areas including furnaces, dry boxes, and hoods is passed through HEPA filters before it is exhausted. For room exhaust, a minimum of eight changes per hour are maintained and cell exhaust is filtered through a roughing filter and two HEPA filters. Exhaust from all glove boxes is filtered through a roughing filter and three HEPA filters. Open hoods and boxes discharging into the process gaseous system have a roughing filter and two HEPA filters.

Nuclear Fuel Services - Erwin, Tennessee (3-22)

Fabrication capacity of the Nuclear Fuel Services fabrication plant is roughly 50 MTU/year. The major facilities at this plant, which are discussed below, are a low-enriched uranium facility, a high-enriched uranium facility, and a plutonium facility. Air flow through these facilities are controlled by pressure zonation. Other important activities at the plant include ^{233}U scrap recovery, highly enriched uranium scrap recovery, uranium and thorium pelletizing, thorium dioxide production, and uranium and thorium metal production.

Low-enriched uranium fuel fabrication facility:

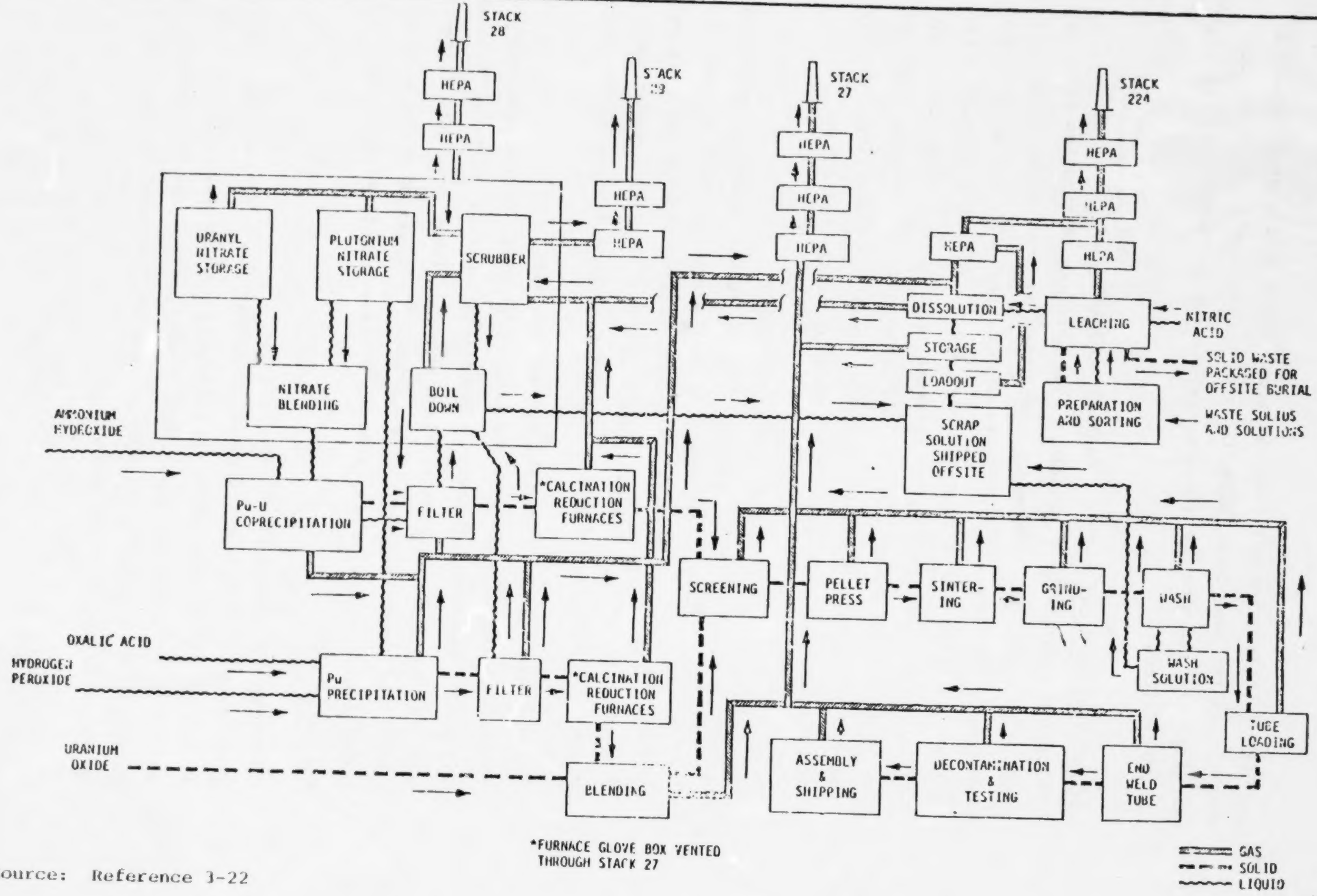
Process gaseous waste is passed through either ammonium hydroxide or potassium hydroxide scrubbers or two stages of HEPA filtration. Low-enriched uranium effluent from HEPA filtered streams and from wet scrubbers are $5x10^{-8}$ uCi/sec, and $1.13x10^{-8}$ uCi/sec, respectively. Data on the control systems are given in Figure 3.9 and Table 3-12.

High-enriched uranium fuel fabrication facility:

Process gaseous streams are passed through HEPA filters and venturi and packed bed wet scrubber. Ventilation air is filtered through Cambridge filters. High-enriched uranium effluent from HEPA filtered stream and from scrubber streams are 2 pCi/sec and 100 pCi/sec, respectively. Data on the control systems are given in Figure 3.10 and Table 3-13.

Plutonium fuel fabrication facility:

Four stack effluents are treated by either two or three HEPA filters in series or by two HEPA filters utilized in conjunction with a scrubber. Plutonium and uranium effluents from the system are $2.0x10^{-8}$ to $1.4x10^{-9}$ uCi/sec. Data on the control systems are given in Figure 3.11 and Table 3-14.


STACK 28
STACK 23
STACK 27
STACK 224
HEPA
URANYL NITRATE STORAGE
PLUTONIUM NITRATE STORAGE
SCRUBBER
DISSOLUTION
LEACHING
NITRIC ACID
STORAGE
LOADOUT
SOLID WASTE PACKAGED FOR OFFSITE BURIAL
PREPARATION AND SORTING
WASTE SOLIDS AND SOLUTIONS
NITRATE BLENDING
BOIL DOWN
AMMONIUM HYDROXIDE
SCRAP SOLUTION SHIPPED OFFSITE
Pu-U COPRECIPITATION
FILTER
*CALCINATION REDUCTION FURNACES
SCREENING
PELLET PRESS
SINTER-ING
GRINDING
WASH
WASH SOLUTION
OXALIC ACID
HYDROGEN PEROXIDE
Pu PRECIPITATION
FILTER
*CALCINATION REDUCTION FURNACES
TUBE LOADING
URANIUM OXIDE
BLENDING
ASSEMBLY & SHIPPING
DECONTAMINATION & TESTING
END WELD TUBE
GAS
SOLID
LIQUID

*FURNACE GLOVE BOX VENTED THROUGH STACK 27

Source: Reference 3-22

LOW ENRICHED URANIUM OXIDE FACILITY BLDG. 301

DAMES & MOORE

FIGURE 3.9

TABLE 3-12

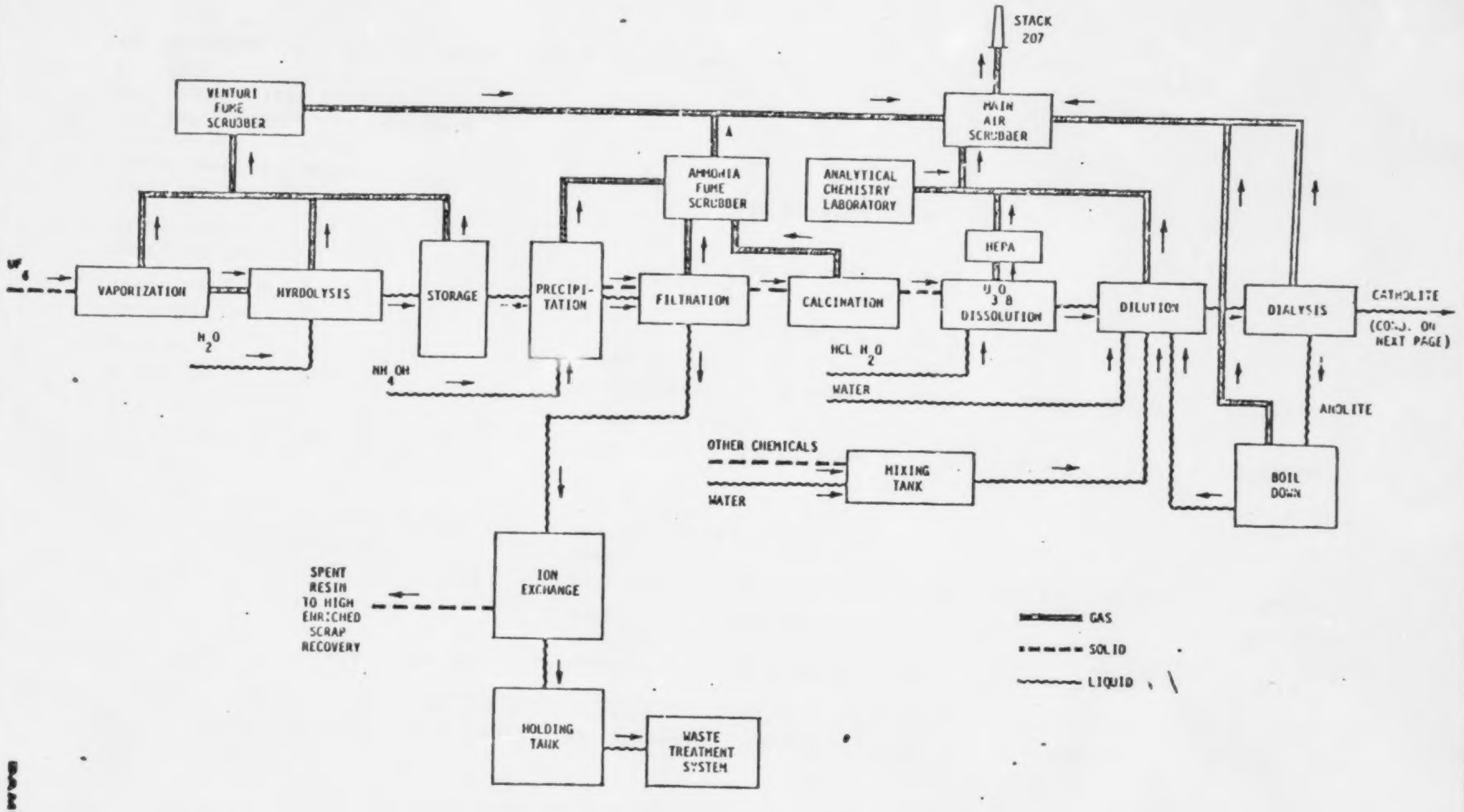
Gaseous Effluent from the Low Enriched Uranium Oxide Facility Building 301*

Release Point and Height	Control Devices	Efficiency percent	Operational Checks	Potential Contaminant	Flow Rate cfs	Concentration uCi/mlx10^{-12}		Emission Rate[d] uCi/sec
						Avg	Max	
Stack 159 (15.2 m)	2 HEPA filters in series	99.999	Sample analyzed daily	LE Uranium	53.3	0.20[a]	5.60	2.5x10^{-8}
Stack 197 (15.2 m)	2 air scrubbers in parallel	95(est)	Fans and pumps checked daily; Sample analyzed daily	Particulates LE Uranium	15.0	0.32[a]	12.0	0.001 lb/hr 1.13x10^{-8}
Stack 198 (15.2 m)	None		Sample analyzed daily	LE Uranium	9.7	0.32[b]	3.0	7.33x10^{-9}
Stack 292 (2.4 m)	None		Sample analyzed daily	LE Uranium	36.7	2.97[c]	41.0	2.57x10^{-7}
Vent fan 1st floor west (2.4 m)				LE Uranium	36.7			
Vent fan 2nd floor south				LE Uranium	36.7			
Vent fan 3rd floor west (5.5 m)				LE Uranium	36.7			

(a) 1972 to February 1975 data
(b) 1973 to 1974 data
(c) 1973
(d) Emission rates are in uCi/sec unless otherwise noted.

---

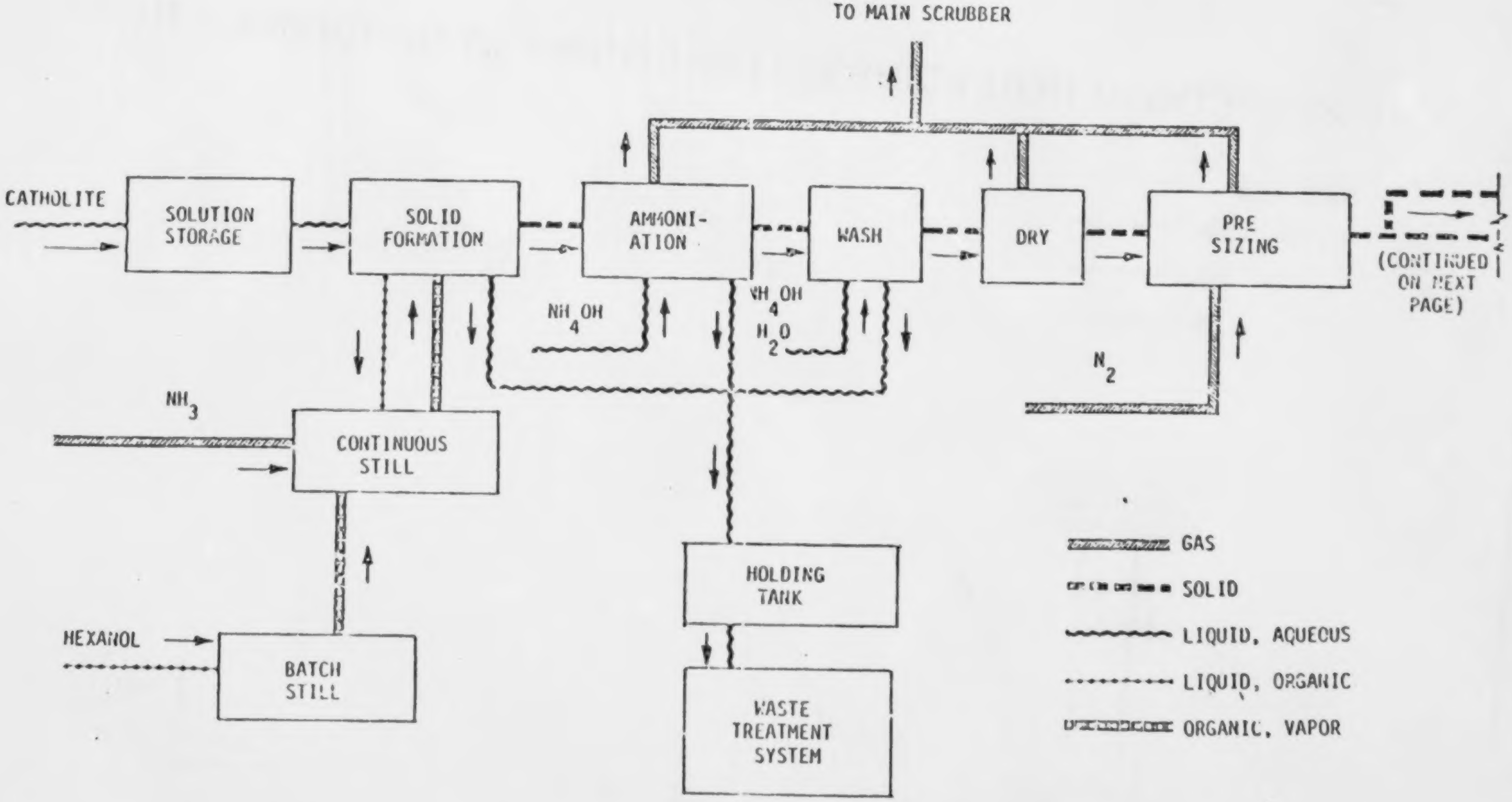
* Source : Ref 3-22.


STACK 207
VENTURI FUME SCRUBBER
MAIN AIR SCRUBBER
AMMONIA FUME SCRUBBER
ANALYTICAL CHEMISTRY LABORATORY
HEPA
UF4
VAPORIZATION
HYRDOLYSIS
STORAGE
PRECIPITATION
FILTRATION
CALCINATION
U3O8 DISSOLUTION
DILUTION
DIALYSIS
CATHOLITE
(CONJ. ON NEXT PAGE)
H2O
NH4OH
HCL H2O
WATER
ANOLITE
OTHER CHEMICALS
WATER
MIXING TANK
BOIL DOWN
ION EXCHANGE
SPENT RESIN TO HIGH ENRICHED SCRAP RECOVERY
HOLDING TANK
WASTE TREATMENT SYSTEM
GAS
SOLID
LIQUID

HIGHLY ENRICHED URANIUM FUEL FABRICATION BLDGS.302-303

Source: Reference 3-22

FIGURE 3.10

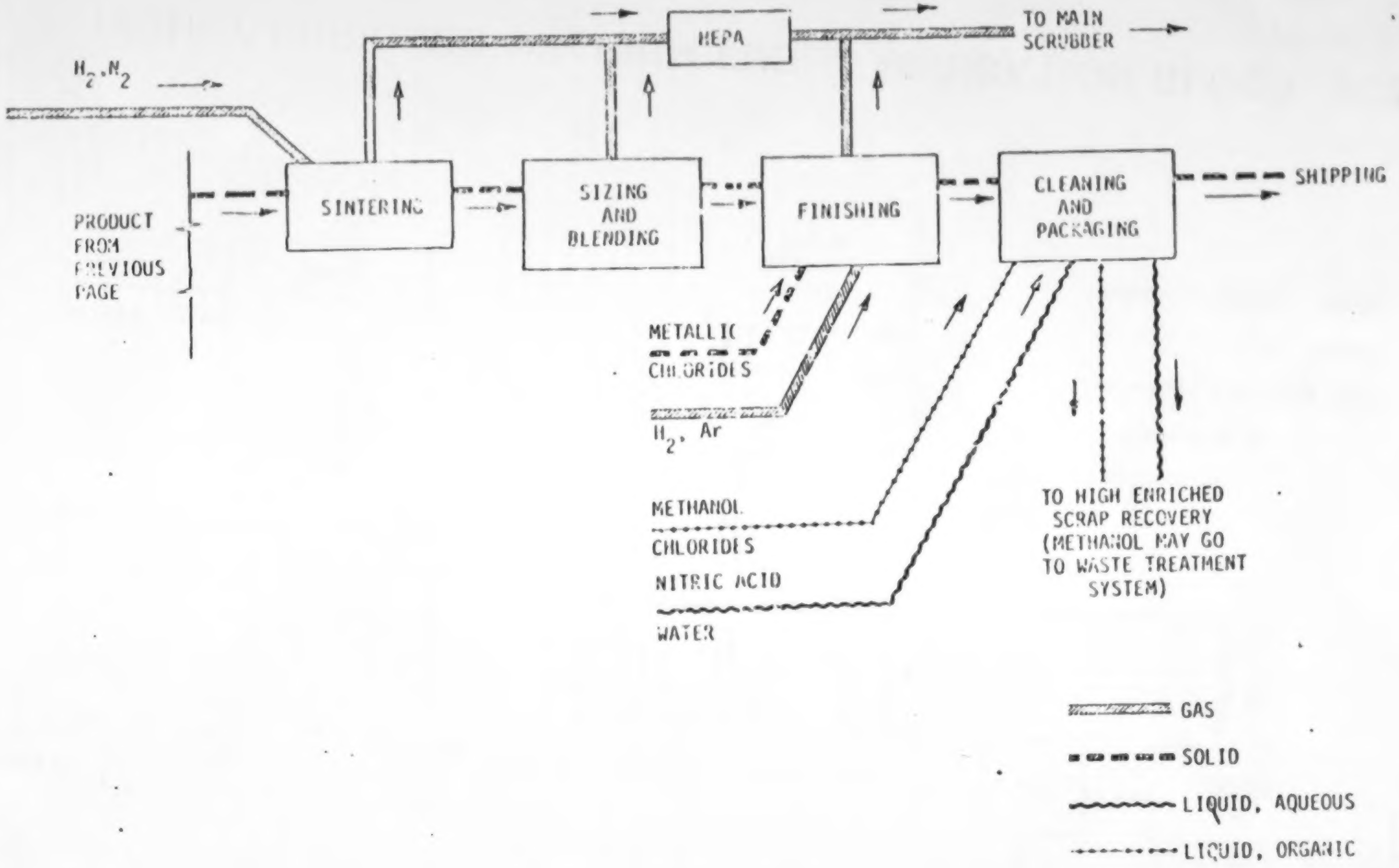

TO MAIN SCRUBBER
CATHOLITE
SOLUTION STORAGE
SOLID FORMATION
AMMONI- ATION
WASH
DRY
PRE SIZING
(CONTINUED ON NEXT PAGE)
NH_4OH
NH_4OH
H_2O
N_2
NH_3
CONTINUOUS STILL
HEXANOL
BATCH STILL
HOLDING TANK
WASTE TREATMENT SYSTEM
GAS
SOLID
LIQUID, AQUEOUS
LIQUID, ORGANIC
ORGANIC, VAPOR

HIGHLY ENRICHED URANIUM FUEL FABRICATION BLDGS. 302-303

CONTINUED

Source: Reference 3-22

FIGURE 3.10 (CONTINUED)


H_2,N_2
PRODUCT FROM PREVIOUS PAGE
SINTERING
SIZING AND BLENDING
FINISHING
CLEANING AND PACKAGING
HEPA
TO MAIN SCRUBBER
SHIPPING
METALLIC CHLORIDES
H_2, Ar
METHANOL
CHLORIDES
NITRIC ACID
WATER
TO HIGH ENRICHED SCRAP RECOVERY (METHANOL MAY GO TO WASTE TREATMENT SYSTEM)
GAS
SOLID
LIQUID, AQUEOUS
LIQUID, ORGANIC

HIGHLY ENRICHED URANIUM FUEL FABRICATION BLDGS. 302-303

CONTINUED

Source: Reference 3-22

DAMES & MOORE

FIGURE 3.10 (CONTINUED)

TABLE 3-13

Gaseous Effluents from Finished Product Fabrication, Building 302-3*

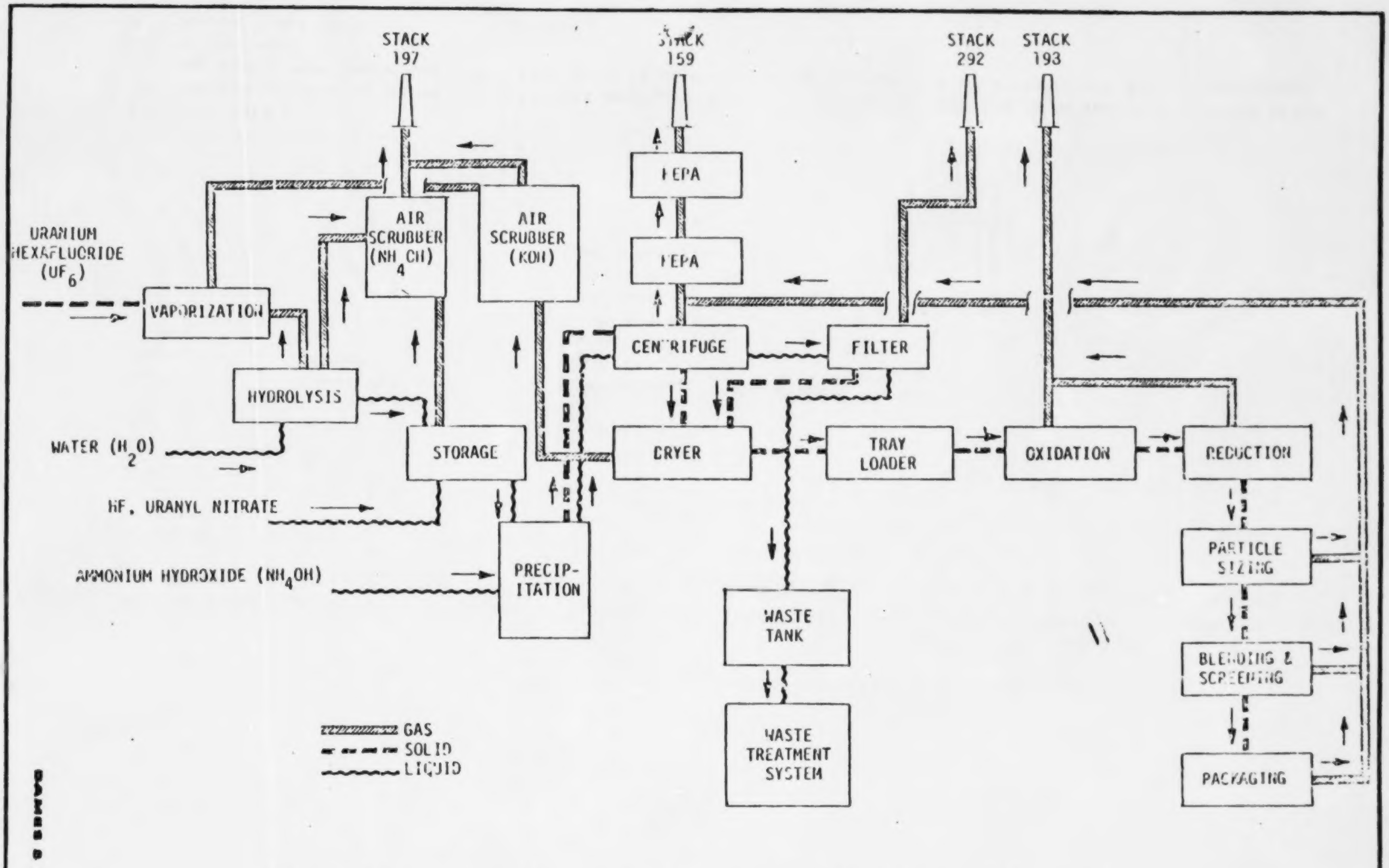
Release Point and Height	Control Devices	Efficiency percent	Operational Checks	Potential Contaminant	Flow Rate cfs	Concentration uCi/mlx10^{-12} Avg	Concentration uCi/mlx10^{-12} Max	Emission Rate uCi/sec
Stack 207 (15.8m)	HEPA	99.97	Fan and Pump checked daily; Sample analyzed daily	HE insoluble uranium	317.0	2.67[a]	83.18	2.0×10^{-6}
	Venturi & packed bed wet scrubber	Unknown		HE soluble uranium		65.44[b]	850.00	1.0×10^{-4}
Roof vents (6.7m)	Cambridge filter	83 for 0.3 micron particle	Breathing air is monitored continously. Effluent is sampled periodically.	HE uranium	628.3 total			

(a) 1974 data

(b) Soluble uranium in stack 207 effluents averaged 210×10^{-12} uCi/ml in 1973 due to a demister problem which has since been corrected. The 1974 data is expected to be represented of current and future operations.

---

* Source : Ref 3-22.


STACK 197
STACK 159
STACK 292
STACK 193
URANIUM HEXAFLUORIDE (UF_6)
VAPORIZATION
HYDROLYSIS
WATER (H_2O)
HF, URANYL NITRATE
AMMONIUM HYDROXIDE (NH_4OH)
AIR SCRUBBER (NH_4OH)
AIR SCRUBBER (KOH)
STORAGE
PRECIP-ITATION
HEPA
HEPA
CENTRIFUGE
FILTER
DRYER
TRAY LOADER
OXIDATION
REDUCTION
PARTICLE SIZING
BLENDING & SCREENING
PACKAGING
WASTE TANK
WASTE TREATMENT SYSTEM
GAS
SOLID
LIQUID

PLUTONIUM FUEL RCD FABRICATION BLDG. 234

Source: Reference 3-22

FIGURE 3.11

TABLE 3-14

Gaseous Effluents from Building 234*
(Plutonium Fuel Fabrication Facility)

Release Point and Height	Control Devices	Efficiency[a] percent	Operational[b] Checks	Potential Contaminant	Flow Rate cfs	Concentration μCi/ml x 10^{-12}		Emission Rate uCi/sec
						Avg	Max	
Stack 27 (4.6m)	3 HEPA in series	100	Sample analyzed daily	Pu + U	30.05	0.03^c	0.89	2.13×10^{-9}
Stack 28 (4.6m)	2HEPA in series	99.999	Sample analyzed daily	Pu + U	13.8	0.05^d	2.39	1.63×10^{-9}
Stack 29 (7.6m)	Air scrubber 2 HEPA in series	Unknown 99.999	Fan and pump checked daily; Sample analyzed daily.	Pu + U	19.8	0.03^c	0.62	1.4×10^{-9}
Stack 224 (9.1m)	3 HEPA in series	100	Sample analyzed daily	Pu + U	23.3	0.13^d	2.76	2.08×10^{-8}
Stack 51 (12.2m)	Air scrubber Charcoal filter HEPA	Unknown Unknown 99.97	Fan and pump checked daily; sample analyzed daily.	^{233}U Radon	16.2	0.64^c 2000	7.00	2.45×10^{-8}
Stack 36 (11.9m)	Charcoal filter HEPA	Unknown 99.97	Sample analyzed daily	^{233}U Radon	13.2	1.31^a 2000	31.08	4.08×10^{-8}

(a) Efficiency for 0.3 micron diameter particles.
(b) Operational checks are performed only when the facility or ventilation system is in opeartion.
(c) 1973 to February 1975
(d) 1972 to February 1975

---

* Source : Ref 3-22.

Westinghouse - Columbia, South Carolina (Ref 3-23)
At this plant only low-enriched uranium is handled. HEPA filtration is the predominant form of control used. Much of the process gas is passed through venturi, impingement, packed tower, or high energy venturi cyclone scrubbers. System effluent is approximately 27 uCi/week of alpha activity.

Recently, cost-benefit studies of radioactive waste treatment systems for LWR uranium oxide and mixed oxide fuel fabrication plants were performed by the Environmental Studies Division of the Oak Ridge National Laboratory (3-13 and 3-14). In these studies model plants equipped with currently available control technology are described and the costs and resulting dose commitments are delineated. Additional cost and dose commitment data are presented for cases where additional waste treatment equipment has been added. A summary of the results of these studies is presented below.

The model uranium oxide fuel fabrication plant processes 5 MTU per day 300 days/year. For the ADU process (see Figure 3.7), the process off-gas and the ventilation flow rates are about 69,000 scfm and 90,000 scfm, respectively. For the DC process (see Figure 3.8), the process off-gas and the ventilation flow rates are about 19,000 scfm and 90,000 scfm, respectively.

For the ADU process plant four cases are considered. Case 1 has only wet scrubbers in the process off-gas waste system and roughing filters on the ventilation system. In Case 2, 69 and 90 HEPA filters each with 1000 cfm capacity are added to the process and the ventilation system, respectively. The particulate removal efficiency for the HEPA filters used is rated at a low value of 95% for particles greater than 0.3 um, because the system described in Case 2 is not suited for in-place DOP testing of the filter banks. The HEPA filters are considered ready for replacement when the pressure drop across the filter exceeds some pre-determined value. It is expected that the filters will be replaced on a semi-annual basis. In Case 3, the control technology is quite similar to Case 2 except that the process and ventilation gas streams are designed such that in-place DOP testing of the HEPA filters can be accomplished. In Case 4, a second HEPA bank is added and both banks are designed such that in-place DOP testing can be accomplished. The relevant data on ADU cases are presented in Table 3-15.

For the DC process plant four cases were considered (see Figures 3.12 through 3.15). The gaseous waste treatment system for the DC process is complicated by the presence of large quantities of hydrofluoric acid (HF) in the off-gas. The large concentration of HF (about 35% HF by volume) in the gaseous stream can seriously damage standard asbestos and boron-fiberglass HEPA filters. This factor creates the need for considerable HF removal equipment as well as HF-resistant quartz HEPA filters.

For all the DC cases evaluated the effluent is first passed through sintered-nickel filters. In Case 1, the process off-gas stream is passed through a tower filled with crushed limestone where 90% removal of HF occurs which precludes the use of HEPA filters due to high residual HF content. The hydrogen in the effluent is burned before the stream is released to the atmosphere. In Case 2, the limestone tower is replaced by a KOH spray scrubber to reduce the HF concentration by a factor of 10^7. The gaseous stream is diluted with air to reduce the concentration of hydrogen below its lower explosive limit. The ventilation stream is equipped with roughing filters as well as a single bank of HEPA filters. In Case 3, HF removal is improved by the incorporation of an HF condenser in the system upstream of the KOH scrubber. This water-cooled HF condenser is capable of reducing the HF concentration by 90% with a 45% HF solution available for recycling. After the gaseous stream enters the scrubber, the HF concentration is reduced to a level one-third of that observed in Case 2 stream after scrubbing. The process gaseous stream

TABLE 3-15

ADU Process Model Fuel Fabrication Plant (1500 MTU/yr)
Gaseous Waste Treatment Data

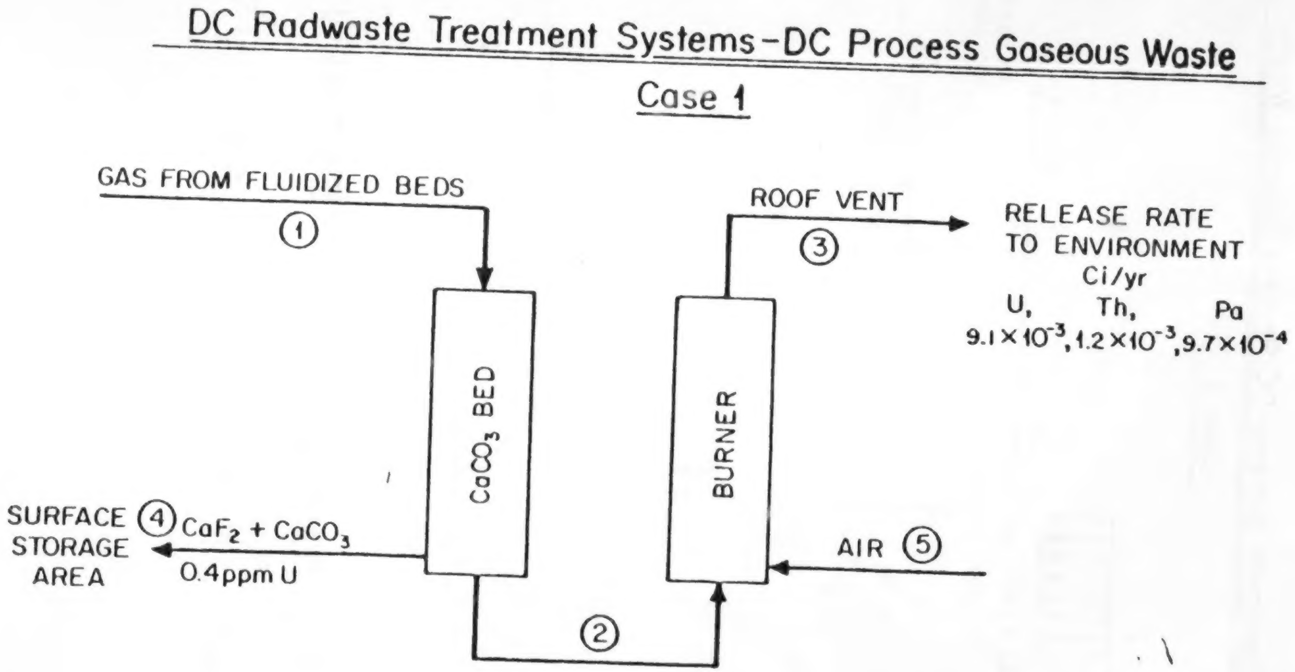
Case and Control*	Capital Costs** [Annual Costs] Thousands of $	Efficiency %	Effluent (Ci/yr)	Annual Residuals
Case 1				
PG : Wet Scrubber	202	Not Available	Gross- = 1.8E+5***	Unknown amount of scrubber waste
VG : Roughing Filters	[184]		Gross- = 4.4E+4	
Case 2				
PG : Wet Scrubber Plus One Bank of HEPA Filters (no in-place testing)	763	95	Gross- = 9.2E+3	318 spent HEPA filters plus unknown amount of scrubber waste
VG : Roughing Filters Plus One Bank of HEPA Filters (no in-place testing)	[345]		Gross- = 2.2E+3	
Case 3				
PG : Wet Scrubber Plus One Bank of HEPA Filters (in-place testing)	1102	99.95	Gross- = 9.2E+1	1908 spent HEPA filters plus unknown amount of scrubber waste
VG : Roughing Filters Plus One Bank of HEPA Filters (in-place testing)	[453]		Gross- = 2.2E+1	
Case 4				
PG : Wet Scrubber Plus Two Banks of HEPA Filters (in-place testing)	1805	99.995	Gross- = 9.2E-1	3816 spent HEPA filters plus unknown amount of scrubber waste
VG : Roughing Filters Plus Two Banks of HEPA Filters (in-place testing)	[700]		Gross- = 2.2E-1	

Source : Ref 3-13.

* PC : Process Gas Stream ; VG : Ventilation Gas Stream

** 1978 dollars obtained from 1973 dollars given in (3-13) by multiplying with 1.467 based on the Consumer Price Index listing.

*** Exponential Notation, e.g., 1.8E+5 = 1.8×10^5.


DC Radwaste Treatment Systems-DC Process Gaseous Waste
Case 1
GAS FROM FLUIDIZED BEDS
①
CaCO3 BED
②
BURNER
ROOF VENT
③
RELEASE RATE TO ENVIRONMENT
Ci/yr
U, Th, Pa
9.1×10-3, 1.2×10-3, 9.7×10-4
AIR ⑤
SURFACE STORAGE AREA
④ CaF2 + CaCO3
0.4ppm U

DC RADWASTE TREATMENT
SYSTEMS-DC PROCESS GASEOUS WASTE
CASE 1

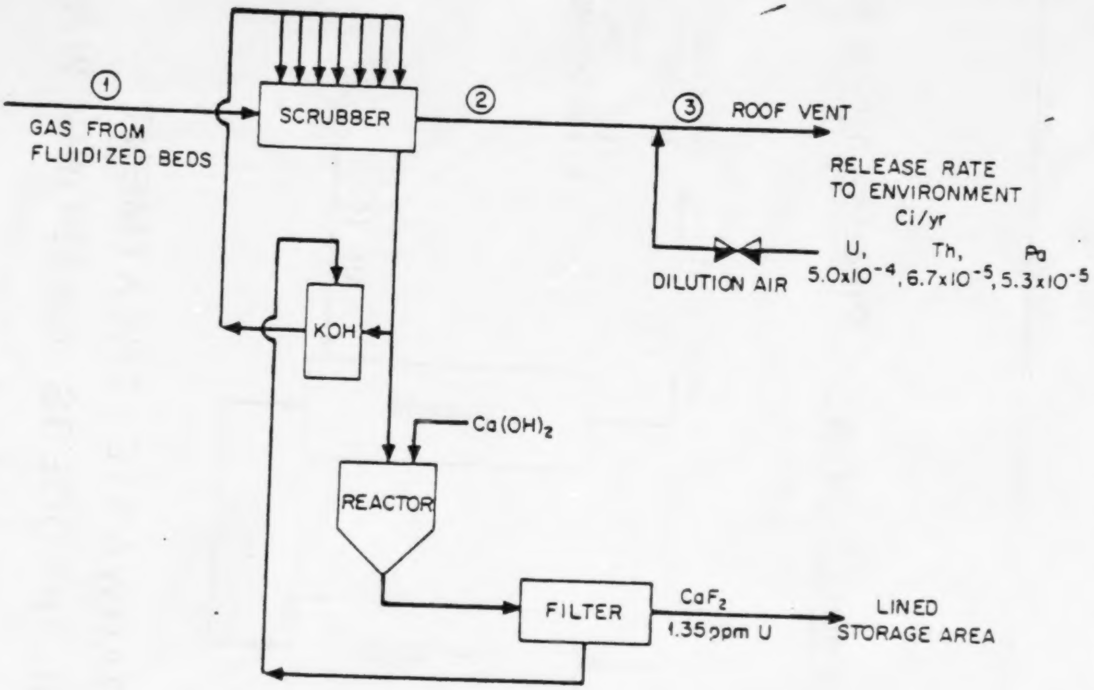
Source: Reference 3-13

DAMES & MOORE

FIGURE 3.12

DC Radwaste Treatment Systems-DC Process Gaseous Waste

Case 2



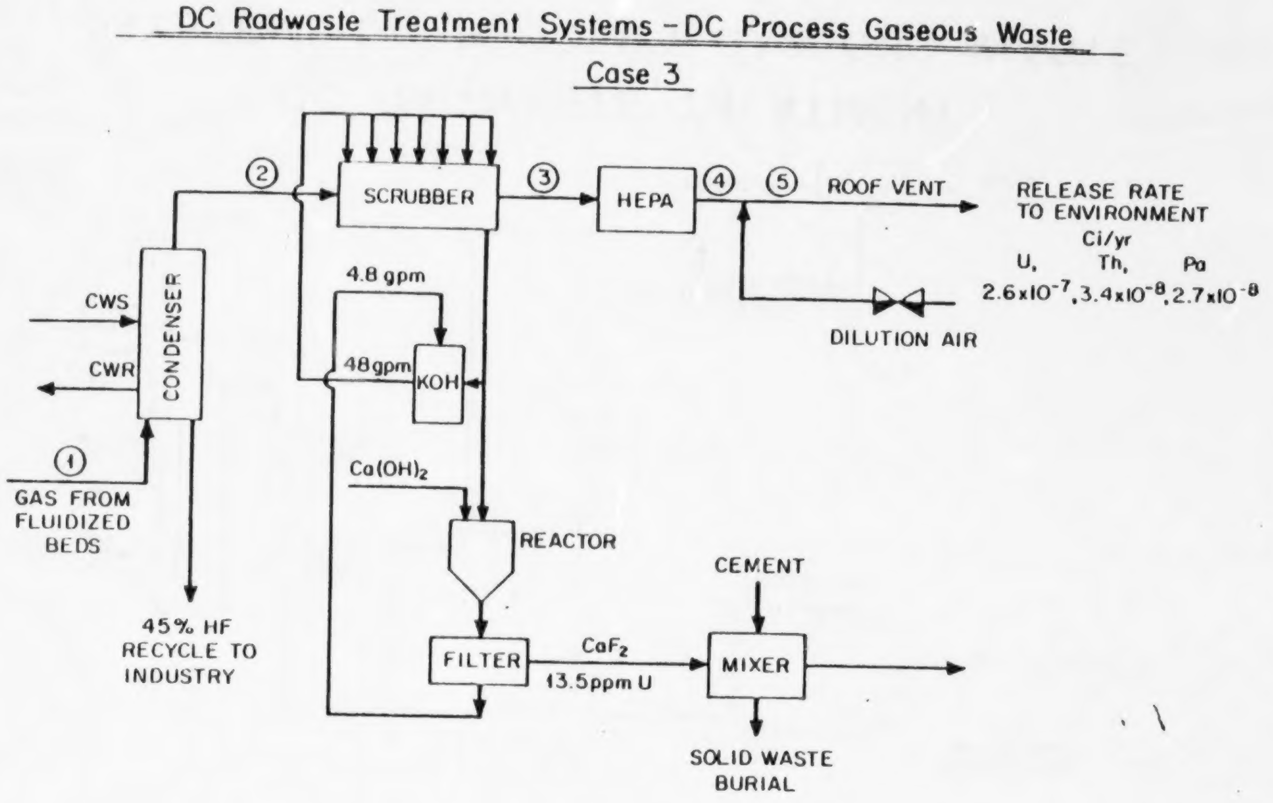
①
GAS FROM FLUIDIZED BEDS
SCRUBBER
②
③
ROOF VENT
RELEASE RATE TO ENVIRONMENT Ci/yr
U, Th, Pa
5.0x10⁻⁴, 6.7x10⁻⁵, 5.3x10⁻⁵
DILUTION AIR
KOH
Ca(OH)₂
REACTOR
FILTER
CaF₂
1.35 ppm U
LINED STORAGE AREA

DC RADWASTE TREATMENT
SYSTEMS-DC PROCESS GASEOUS WASTE
CASE 2

Source: Reference 3-13

DAMES & MOORE

FIGURE 3.13


DC Radwaste Treatment Systems - DC Process Gaseous Waste
Case 3
CWS
CWR
① GAS FROM FLUIDIZED BEDS
CONDENSER
45% HF RECYCLE TO INDUSTRY
②
SCRUBBER
③
HEPA
④
⑤
ROOF VENT
RELEASE RATE TO ENVIRONMENT
Ci/yr
U, Th, Pa
2.6x10-7, 3.4x10-8, 2.7x10-8
DILUTION AIR
4.8 gpm
48 gpm
KOH
Ca(OH)2
REACTOR
FILTER
CaF2
13.5 ppm U
CEMENT
MIXER
SOLID WASTE BURIAL

DC RADWASTE TREATMENT
SYSTEMS-DC PROCESS GASEOUS WASTE

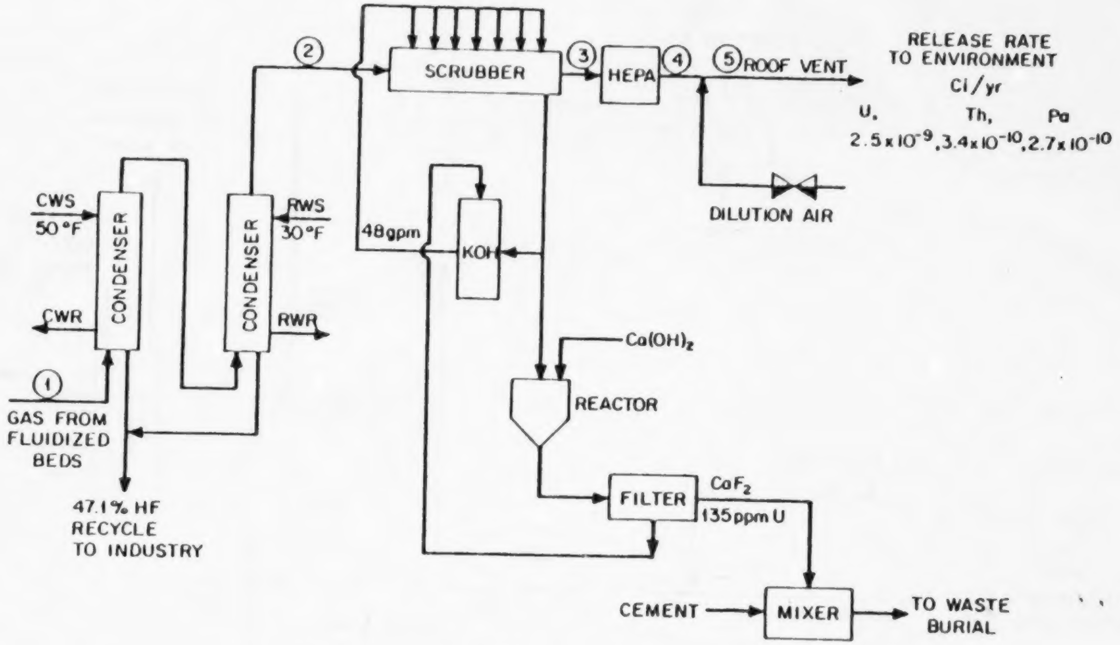
CASE 3

Source: Reference 3-13

FIGURE 3.14

DC Radwaste Treatment Systems – DC Process Gaseous Waste

Case 4


②
SCRUBBER
③
HEPA
④
⑤ ROOF VENT
RELEASE RATE TO ENVIRONMENT
Ci/yr
U, Th, Pa
2.5 x 10⁻⁹, 3.4 x 10⁻¹⁰, 2.7 x 10⁻¹⁰
DILUTION AIR
CWS 50 °F
CONDENSER
CONDENSER
RWS 30 °F
48 gpm
KOH
CWR
RWR
Ca(OH)₂
①
GAS FROM FLUIDIZED BEDS
REACTOR
47.1% HF RECYCLE TO INDUSTRY
FILTER
CaF₂
135 ppm U
CEMENT
MIXER
TO WASTE BURIAL

DC RADWASTE TREATMENT SYSTEMS-DC PROCESS GASEOUS WASTE

CASE 4

Source: Reference 3-13

FIGURE 3.15

is then passed through a single bank of HF-resistant HEPA filters. The ventilation gaseous stream is passed through roughing filters and then a single bank of standard HEPA filters. In Case 4, HF removal is improved by the addition of a brine-cooled condenser downstream of the water-cooled condenser utilized in Case 3. The addition of this condenser results in a HF recovery of approximately 99%. The solid residue volume of CaF_2 is substantially reduced between Case 2 (4.33 metric-tons/day) and Case 4 (43 kg/day). Downstream of the KOH scrubber on the process gas line are two HF-resistant HEPA filter banks capable of being DOP tested in-place. The ventilation gas stream is passed through a roughing filter and two banks of standard HEPA filters. The relevant data for DC process cases are given in Table 3-16.

For a mixed oxide (PuO_2 and UO_2) fuel fabrication plant, the air cleaning technology is more complicated and expensive because of the higher radiotoxicity of the feed. The cost-benefit study performed (3-14) on mixed oxide fuel fabrication plants describes a model plant processing 300 metric tons of LWR plutonium recycle fuel with a combined ventilation and process off-gas flow rate of 120,000 cfm. The data on the three treatment cases considered in the study are given in Table 3-17.

Non-LWR Fuel Fabrication Plants

There also are a number of fuel fabrication plants in the United States that produce fuel for non-LWRs such as high temperature gas cooled reactors (carbide fuels), experimental reactors (Pu fuel, U metal), test reactors (enriched U), research reactors (depleted U), etc. A partial list of these plants were presented in Table 3-10. The data obtained from NRC Special Nuclear Material licenses and/or license applications of several plants are given below. Capital costs for installation of the control technologies and annual operating costs could not be obtained. A discussion of capital costs for HEPA

TABLE 3-16

DC Process Model Fuel Fabrication Plant (1500 MTU/yr)
Gaseous Waste Treatment Data

Case and Control*	Capital Costs** [Annual Costs] Thousands of $	Efficiency %	Effluent (Ci/yr)	Annual Residuals
Case 1				
PG : Crushed Limestone Tower, H_2 Burner, Solid Waste stored in unlined area VG : Roughing Filters	93 [145]	Not Available	Gross- = 1.4E+5*** Gross- = 3.3E+4	1336 MT of CaF_2 777 MT of $CaCO_3$
Case 2				
PG : KOH Scrubber, Lime Regeneration of KOH, H_2 dilution, Solid waste stored in lined area VG : Roughing Filters	747 [320]	Not Available	Gross- = 7.2E+3 Gross- = 1.7E+3	136 spent HEPA filters plus 1298 MT of CaF_2
Case 3				
PG : Single-pass HF condensor, KOH scrubber, lime regeneration of KOH, HEPA filter, incorporate CaF_2 waste in cement, H_2 dilution. VG : Roughing Filter Plus HEPA Filter	1546 [386]	99.95	Gross- = 6.7E+1 Gross- = 1.6E+1	1344 spent HEPA filters plus 130 MT of CaF_2
Case 4				
PG : Multiple-pass HF condensor, 99% HF recovery, KOH scrubber, lime regeneration of KOH, HEPA filters in series, incorporate CaF_2 waste in cement, H_2 dilution. VG : Roughing Filter Plus HEPA Filters in Series	1805 [700]	99.9995	Gross- = 6.7E-1 Gross- = 1.6E-1	2688 spent HEPA filters plus 13 MT of CaF_2

Source : Ref 3-13.

* PG : Process Gas Stream ; VG : Ventilation Gas Stream

** 1978 dollars obtained from 1973 dollars given in (3-13) by multiplying with 1.467 based upon the Consumer Price Index listing.

*** Exponential Notation, e.g., 1.4E+5 = 1.4×10^5.

TABLE 3-17

Model Mixed Oxide Fuel Fabrication Plant (1500 MTU/yr)
Gaseous Waste Treatment Data

Case and Control	Capital Costs* [Annual Costs] Thousands of $	Decontamination Factors**	Effluent (Ci/yr)	Annual Residuals
Case 1 Five Parallel HEPA Filter Modules, each with two in-series banks of 30 Filters, within a housing with a flow rating of 30,000 cfm. Each module has 40,000 cfm blower with dampers for isolation of modules during filter replacement or DOP testing.	3,278 [917]	PG : 8.0E+7*** VG : 8.0E+6	Total Pu = 5.9E-5 Total U = 7.4E-10 Am-241 = 4.3E-6	150 Spent HEPA Filters
Case 2 Same as Case 1 with the addition of a third bank of five HEPA modules each containing 30 filters with 1000 cfm each.	4,057 [1,142]	PG : 8.0E+9 VG : 8.0E+8	Total Pu = 5.9E-7 Total U = 7.4E-12 Am-241 = 4.3E-8	255 Spent HEPA Filters
Case 3 Recycling of 98% of the process gas streams and alpha-enclosure ventilation air through one stage of HEPA Filters. The rest of the gaseous stream is treated with two stages of HEPA filters and is then blended with fume hood and plant ventilation air. The total plant gaseous effluent is then passed through two stages of HEPA filters.	5,328 [1,488]	PG : 8.0E+14 VG : 8.0E+13	Total Pu = 5.9E-12 Total U = 7.4E-17 Am-241 = 4.3E-13	193 Spent HEPA Filters

---

Source : Ref 3-14.

* 1978 dollars obtained from 1975 dollars given in (3-14) by multiplying with 1.211 based upon the Consumer Price Index listing.

** PG : Process Gas Stream ; VG : Alpha-enclosyre Ventilation Gas Stream

*** Exponential Notation, e.g., 8.0E+7 = 8.0×10^7.

filter systems is provided in Appendix IIA. Annual effluents of the facilities and system specific efficiencies are given where available.

Battelle-Pacific Northwest Laboratories - Richland, Washington
(3-24) - Plutonium Fuels Laboratory (Bldg - 308)
Air flow through the plant is controlled by pressure zonation. Two HEPA filters in series are employed between any lab area and the atmosphere and three HEPA filters are used between any glove box and the atmosphere. A one to two inch thick fiberglass roughing filter precedes all HEPA filters. The system effluent is less than 2 uCi/yr.

General Atomic - San Diego, California (3-25)
This plant was previously owned by the Gulf Oil Corporation. Air flow through the plant is controlled by pressure zonation. The control systems employed include HEPA filters, 4 soot filters, and 3 fume scrubbers. All but three HEPA units are preceded by prefilters.

General Electric Co. - Vallecitos, California (3-26)
Air flow through the plant is controlled by pressure zonation. The exhaust rate is approximately 35,000 cfm. The main filter bank for exhaust filtration is composed of 20 HEPA filters. Roughing filters are employed upstream of the HEPA units.

U.S. Nuclear, Inc. - Oak Ridge, Tennessee (3-27)
Air flow through the plant is controlled by pressure zonation. The exhaust air from the melting and casting platform and the core degreaser areas is passed through HEPA filters.

Westinghouse Electric Corporation - Cheswick, Pennsylvania (3-28)
Air flow through the plant is controlled by pressure zonation. The exhaust from dry boxes, local exhaust, hoods, and similar devices is passed through HEPA filters. The HEPA number efficiency is in-place tested at 99.97% for particles greater than 0.3 um by DOP smoke.

Central Station Nuclear Power Plants

Central station nuclear power plants presently in operation in the United States consist of light water reactors (LWRs) and a high temperature gas cooled reactor (HTGR). These reactors are licensed by the NRC in accordance with the applicable sections of the Code of Federal Regulations, Title 10 (3-1). Approximately one-third of the 67 LWRs currently in operation are boiling water reactors (BWRs), while the remaining two-thirds are pressurized water reactors (PWRs). A third type of power reactor is the "breeder" reactor. This subsection examines the control technologies employed for reducing the airborne radionuclide releases during routine reactor operation for seven LWRs, one HTGR, and two breeder reactors.

All the LWRs and the HTGR considered have either been issued a post 1972 operating license or a post 1972 construction permit, and their radionuclide release control technology design incorporates presently demonstrated technologies. The "breeder" reactors examined for their radionuclide release control technologies are the Fermi 1 Fast Breeder Reactor (FFBR) (currently shutdown), and the Clinch River Liquid Metal Fast Breeder Reactor (LMFBR) whose construction permit application is pending. The control technologies for the reactors examined in detail are discussed separately below.

Boiling Water Reactors

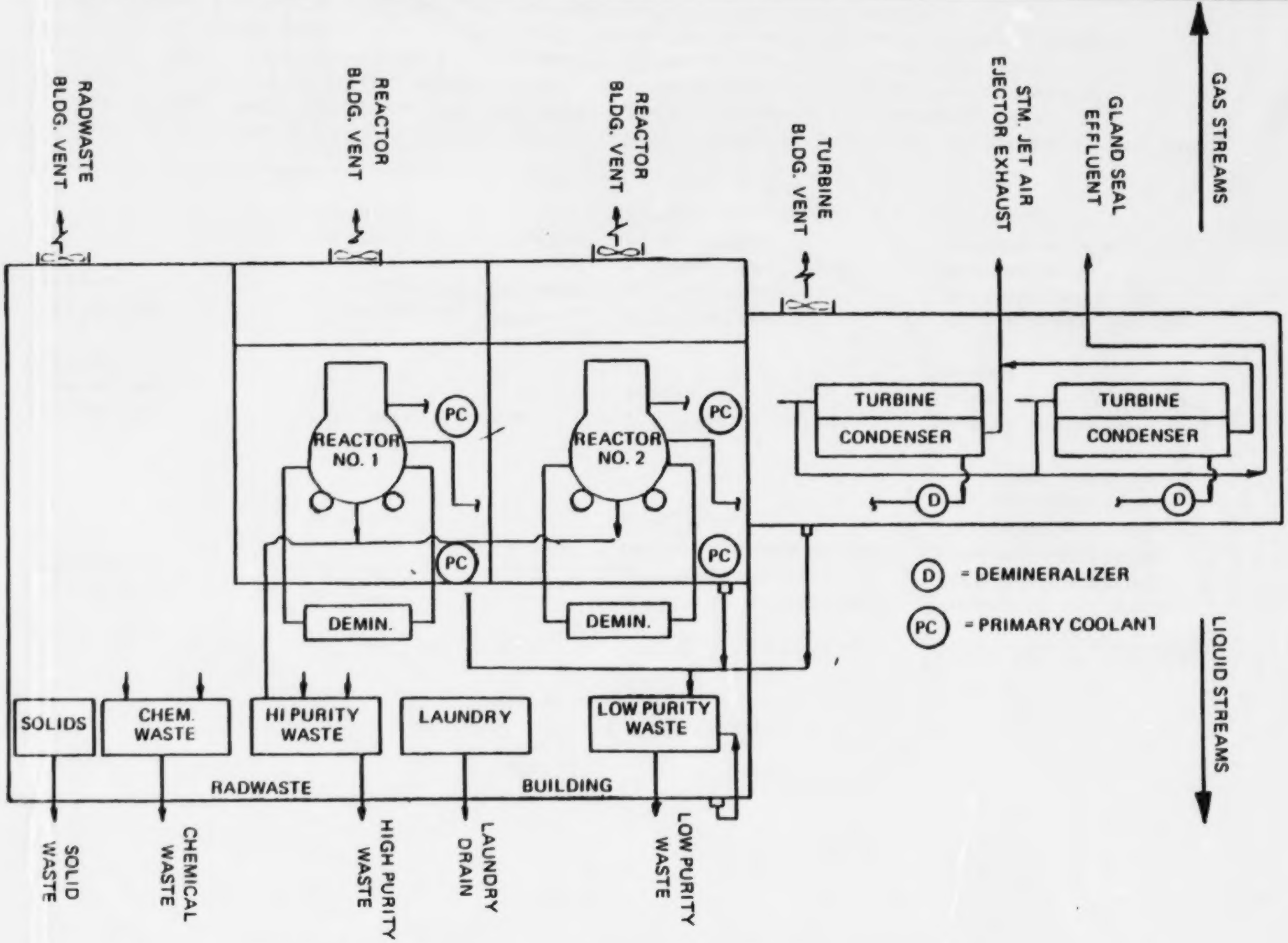
In a BWR, the heat in the reactor core converts part of the cooling/moderating water to steam. The steam expands through a turbine, condenses, and returns to the reactor core. Side streams are withdrawn from the coolant system, processed through a cleaning system, and returned (3-29). The radioactive gases produced in a BWR are activation product gases and fission product gases which are released into the coolant system. Activation product gases result from the irradiation of the reactor coolant and the impurities it contains. Fission product gases result from leaking through normal and/or failed fuel cladding into the coolant. Airborne particulate radionuclides result predominantly from the decay of the radioactive gases (3-31).

The amount of activation gases produced are a function of the reactor power level. The principal activation gases in the steam from the reactor vessel of an 1100 MWe BWR are given below (3-31):

Nuclide	Half-life	Release Rate (uCi/sec)
^{13}N	9.99 min	1.2×10^4
^{16}N	7.13 sec	1.7×10^8
^{17}N	4.14 sec	2.6×10^4
^{19}O	26.8 sec	1.4×10^6
^{18}F	109.8 min	7.2×10^3

Fission product gases include noble gases (principally krypton and xenon isotopes) and halogens, such as iodine. The rate of release of fission product gases is dependent upon the number of failed fuel rods, the size of cladding failures, and fuel rod temperatures. Most of the halogens released from the fuel remain in the reactor coolant rather than pass into the steam phase (3-31).

The major sources of gaseous radionuclides from a BWR are illustrated in Figure 3-16. The principal source of radioactive gaseous effluent to the atmosphere during routine plant operation is the condenser steam-jet air ejector (SJAE) which is a steam driven evacuator that removes non-condensable gases from the main turbine condenser during routine operations (3-31 and 3-32). Less important continuous release points of radioactive gaseous effluent include the turbine gland seal exhaust (TGE), and the ventilation systems for the turbine building, radioactive waste treatement building, and reactor building. The control technologies for the BWRs examined are summarized in Table 3-18 and the control systems are discussed below.


GAS STREAMS
GLAND SEAL EFFLUENT
STM. JET AIR EJECTOR EXHAUST
TURBINE BLDG. VENT
REACTOR BLDG. VENT
REACTOR BLDG. VENT
RADWASTE BLDG. VENT
TURBINE
CONDENSER
TURBINE
CONDENSER
D
D
REACTOR NO. 1
REACTOR NO. 2
PC
PC
PC
PC
DEMIN.
DEMIN.
D = DEMINERALIZER
PC = PRIMARY COOLANT
LIQUID STREAMS
SOLIDS
CHEM. WASTE
HI PURITY WASTE
LAUNDRY
LOW PURITY WASTE
RADWASTE
BUILDING
SOLID WASTE
CHEMICAL WASTE
HIGH PURITY WASTE
LAUNDRY DRAIN
LOW PURITY WASTE

LIQUID AND GASEOUS RADWASTE EFFLUENTS FROM BOILNG WATER REACTORS

Source:

DAMES & MOORE

FIGURE 3.16

TABLE 3-18

Summary of Control Technologies for BWRs Considered

System	J.A. Fitzpatrick(1)	Cooper Station(2)	Peach Bottom 2 & 3(3)
Condenser Steam-Jet Ejector System	Catalytic Recombiner-Ambient Temperature Charcoal Delay System (see Text)	Catalytic Recombiner-Low Temperature Charcoal Delay System (see Text)	Catalytic recombiner followed by 72 hour pressurized piping followed by a roughing and HEPA filter in series (see Text)
Turbine Gland Seal Exhaust System Off-Gas	1.75 minute holdup piping	1.75 minute holdup piping	Routed to Condenser Steam-Jet Air Ejector System
Ventilation Systems	Prefilter and HEPA in series for Radwaste Building; no treatment for Turbine or Reactor Buildings	HEPA filters for the Turbine and Radwaste Buildings; no treatment for Reactor Building.	HEPA filters for the Radwaste Building; no treatment for Turbine or Reactor Buildings.

---

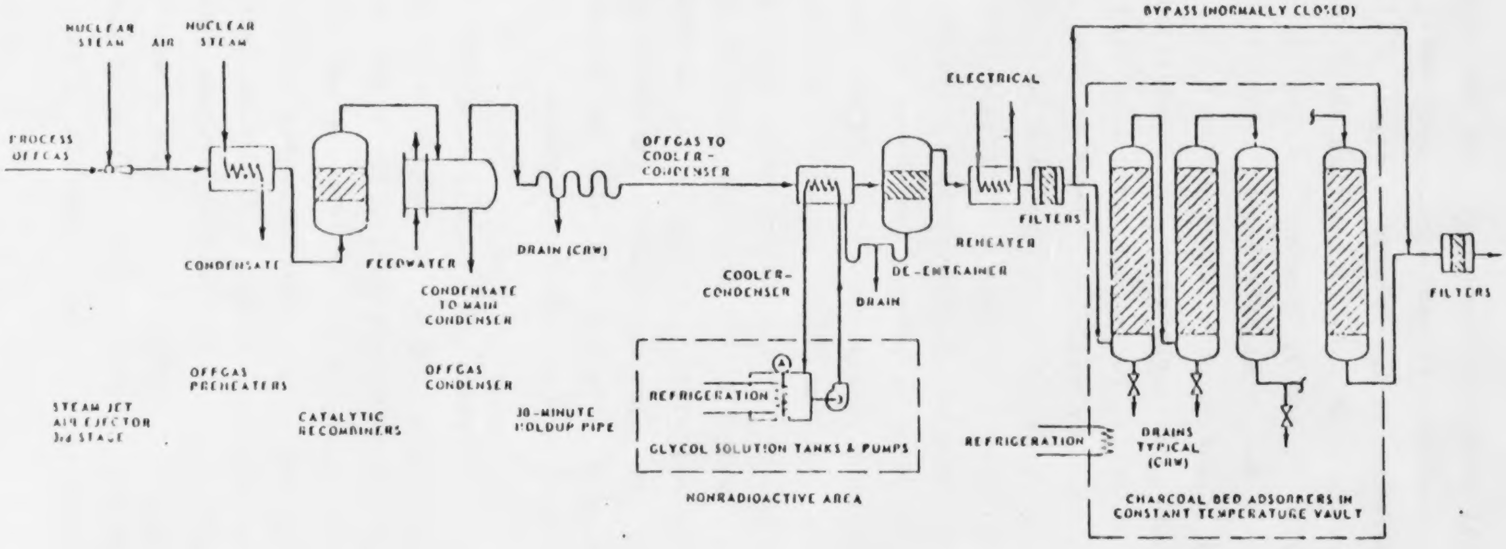
(1) Refs 3-30,3-34; J.A. Fitzpatrick, Oswego County, Power Authority of the State of New York, Operational BWR; Authorized for 821 MW(e); First Criticality : November 1974.

(2) Ref 3-35; Cooper Station, Nemaha County, Nebraska, Nebraska Public Power District, Operational BWR; Authorized for 778 MW(e); First Criticality : February 1974.

(3) Ref 3-36; Peach Bottom 2 & 3, York Co., Pennsylvania, Philadelphia Electric Company, Operational BWRs; Each authorized for 1065 MW(e); First Criticality : Unit 2 in September 1973, Unit 3 in August 1974.

A typical treatment technology for the SJAE system utilizing a combination catalytic recombiner-charcoal delay system operated at ambient temperature is illustrated in Figure 3.17. This type of system is currently in use at J.A. Fitzpatrick which was examined in detail, Browns Ferry 1, 2, and 3; Dresden 1, 2, and 3; Duane Arnold, Hatch 1 and 3; Humboldt Bay, Nine Mile Point 1; Oyster Creek 1; Pilgrim, Quad Cities 1 and 2; and Vermont Yankee plants (3-31). The off-gas, after removal of the condensable gases, is superheated to 350°F and passed through the catalytic recombiner for recombining the gaseous hydrogen and oxygen formed by radiolytic decomposition of water in the core back to water vapor (3-31). The catalytic recombiners reduce the volume of the gaseous effluent and increase operational safety.(3-30) After cooling and moisture removal in a condenser, the gas enters a 30 minute holdup pipe to permit the decay of short lived Kr and Xe isotopes and then passes through a chiller for additional moisture removal. The gas then flows through a deentrainer, a heater which reheats the gas to 77°F, a filter bank, charcoal beds, and an additional filter bank. In the charcoal beds, an adsorption release-readsorption process will delay the Kr and Xe isotopes relative to the carrier gas, thus permitting noble gas decay and deposition of the daughter products. Iodine will also be sorbed by the charcoal and removed by the recombiner/condenser system.

In the J.A. Fitzpatrick SJAE system, the charcoal delay system has twelve, 12-foot long by 38-inch diameter coconut-base activated charcoal beds connected in series (3-30 and 3-34). An approximate holdup time of 240 hours for Xe isotopes and 13 hours for Kr isotopes is provided by the system. Holdup piping before the charcoal beds and after the recombiner provides a 30 minute decay time. Two sets of full-flow HEPA filters in parallel precede release of gases through the main stack. The HEPA filters have a manufacturers design efficiency of 99.97% for particulate of diameter greater than 0.3 microns with a pressure differential across the filter of one inch of water.


PROCESS OFFGAS
NUCLEAR STEAM
AIR
NUCLEAR STEAM
CONDENSATE
FEEDWATER
CONDENSATE TO MAIN CONDENSER
DRAIN (CRW)
OFFGAS TO COOLER-CONDENSER
STEAM JET AIR EJECTOR 3rd STAGE
OFFGAS PREHEATERS
CATALYTIC RECOMBINERS
OFFGAS CONDENSER
30-MINUTE HOLDUP PIPE
COOLER-CONDENSER
A
REFRIGERATION
GLYCOL SOLUTION TANKS & PUMPS
NONRADIOACTIVE AREA
DRAIN
DE-ENTRAINER
REHEATER
ELECTRICAL
FILTERS
BYPASS (NORMALLY CLOSED)
REFRIGERATION
DRAINS TYPICAL (CRW)
CHARCOAL BED ADSORBERS IN CONSTANT TEMPERATURE VAULT
FILTERS

CATALYTIC RECOMBINER-AMBIENT TEMPERATURE
CHARCOAL ADSORBER SYSTEM

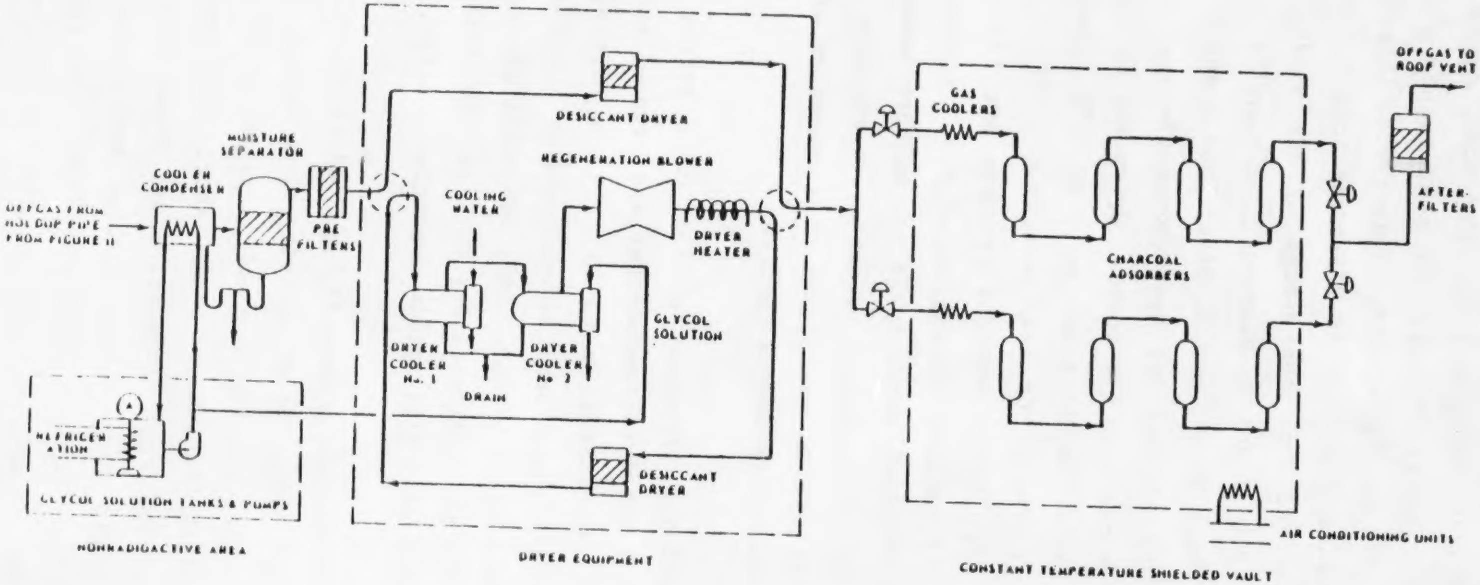
Source: Reference 3-31

FIGURE 3.17

Another treatment technology for the SJAE system utilizing a combination catalytic recombiner-low temperature charcoal delay system is illustrated in Figure 3.18. This system is currently in use at the Cooper Station plant and at Millstone Unit 1. The system has also been incorporated into the design of the Black Fox 1 and 2, Clinton 1, Grand Gulf 1 and 2, Hanford 2, Hartsville 1, 2, 3 and 4, Perry 1 and 2, Phipps Bend 1 and 3, River Bend 1 and 2, and Skagit 1 and 2, plants which are not yet operational (3-33). The system can be operated in the -40°F to 0°F range. Operation in this temperature range and inlet gas drying to a dew point of 90°F (through the use of Mol Sieve beds) increases Kr and Xe holdup (3-31). The catalytic recombiner and associated control systems are the same as those associated with the ambient temperature charcoal systems (3-31). For a 30 minute old modified model noble gas mixture based upon an 18.5 scfm air inleakage, an estimated reduction in activity of 8000 can be obtained with this system, as opposed to a reduction of 16 to 250 for the "ambient" temperature system (3-31).

The SJAE off-gas treatment at the Peach Bottom 2 and 3 power plants utilizes a catalytic recombiner and pressurized holdup piping followed by two HEPA filters (3-36). Each unit has its own air ejector and turbine gland seal off-gas system and the holdup piping provides a 72 hour delay (3-36). Only the noble gases with short half lives and particulate radionuclides will be significantly reduced by the system; radioiodine will not be appreciably affected.

The control technology normally applied to the turbine gland seal exhaust (TGE) for reduction of activity when nuclear steam is used as the turbine sealant is two minute holdup piping (3-29 and 3-31). This allows for substantial decay of the short-lived radionuclides ^{16}N, ^{17}N, and ^{19}O. The J.A. Fitzpatrick and Peach Bottom stations employ nuclear steam to seal the turbine and holdup piping for the turbine gland seal exhaust (3-30 and 3-36). The Peach Bottom Units also have almost complete decay of the short lived radionuclides


OFFGAS FROM HOLDUP PIPE FROM FIGURE 11
COOLER CONDENSER
MOISTURE SEPARATOR
PRE FILTERS
DESICCANT DRYER
REGENERATION BLOWER
COOLING WATER
DRYER HEATER
DRYER COOLER No. 1
DRAIN
DRYER COOLER No. 2
GLYCOL SOLUTION
DESICCANT DRYER
REFRIGERATION
GLYCOL SOLUTION TANKS & PUMPS
NONRADIOACTIVE AREA
DRYER EQUIPMENT
GAS COOLERS
CHARCOAL ADSORBERS
OFFGAS TO ROOF VENT
AFTER-FILTERS
AIR CONDITIONING UNITS
CONSTANT TEMPERATURE SHIELDED VAULT

LOW TEMPERATURE CHARCOAL ADSORBER SYSTEM

SOURCE: REFERENCE 3-31

DAMES & MOORE

since they route the TGE off-gas to the SJAE system which provides the holdup time. If non-reactor derived steam is utilized as the turbine sealant, then the TGE off-gas is no longer an activity release point (3-29 and 3-31). Off-gases from the mechanical vacuum pumps, which remove air during unit startup, are channeled into the gland seal exhaust piping in most reactors (3-29).

Ventilation air from the radioactive waste building is usually passed through filters prior to atmospheric release under normal operating conditions (3-29 and 3-31). Frequently, there are no treatment systems for the ventilation air from the turbine and reactor buildings during normal operating conditions (3-31). The system specific HEPA filter efficiencies and costs could not be obtained. A general discussion of efficiencies and installation costs for HEPA systems can be found in Appendix IIA.

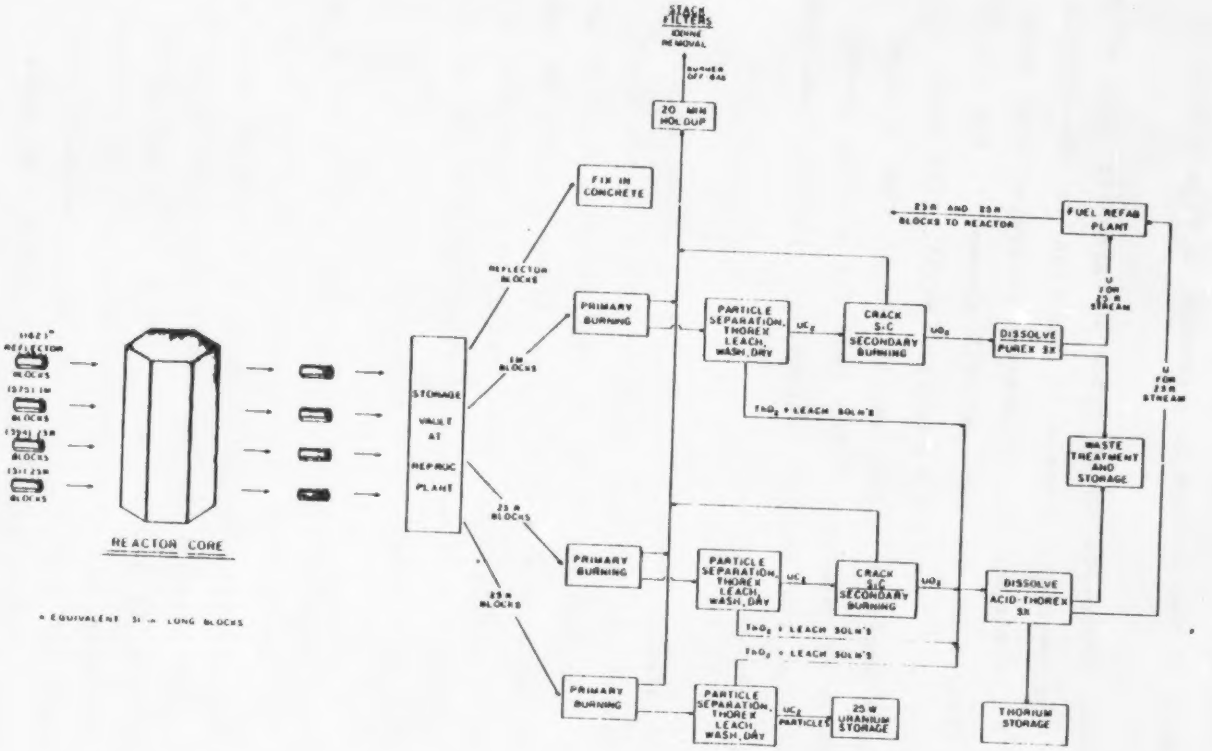
Estimated annual costs for the control of radioactive effluents from routine operations of a model BWR power station consisting of two 1200 MW(e) boiling water reactor units are given in Table 3-19 (3-29). Each model reactor has its own turbine and both turbines are housed in the joint turbine building. There is a common SJAE system, a TGE system, and turbine building ventilation system. The annual cost for each control technology is the sum of the annual operational, maintenance and fixed charges on capital. 1978 dollars obtained from the 1973 dollars given in (3-29) by multiplying it with a factor of 1.467 based upon the Consumer Price Index listing.

The SJAE system of Case 1 in Table 3-19 is similar to the Peach Bottom Units, the SJAE systems of Cases 3 through 5 are similar to the J.A. Fitzpatrick Station, and the SJAE system of Case 6 is similar to the Cooper Station. The SJAE system in Cases 3-5 is estimated to provide a decontamination factor (ratio of the inlet activity concentration to the system outlet concentration) of 1000 for radioiodine composed of an estimated factor of 100 for the recombiner/condenser

TABLE 3-19 : Summary of Annual Costs Applicable to Control of Noble Gases and Iodine Emissions from 2400 MW(e) BWR Stations*

Cases	Steam Jet Air Ejector	Turbine Gland Seal System	Reactor Bldg Ventilation	Turbine Bldg Ventilation	Stack	Totals
Case 1	30-min holdup, HEPA filter	Primary steam, 2 min holdup	No treatment	No treatment	100 meter	
Costs	(191/0)	(7/7)	(0/0)	(0/0)	(100/100)	(298/107)
Case 2	Catalytic recombiner, 30 min holdup, Charcoal adsorber	Primary steam, 2 min holdup	No treatment	No treatment	100 meter	
Costs	(191/314)	(7/7)	(0/0)	(0/0)	(100/431)	(298/745)
Case 3	Catalytic recombiner 30 min holdup, Charcoal delay system, 13-day Xe, 18-hr Kr	Clean steam	Charcoal adsorber	Clean steam on valves 24" dia. and larger	None	
Costs	(365/364)	(147/147)	(0/709)	(0/197)	(0/0)	(512/1417)
Case 4	Catalytic recombiner 30 min holdup, Charcoal delay system, 13-day Xe, 18-hr Kr	Clean steam	Charcoal adsorber	Clean steam on valves 2-1/2 " dia.and larger Internal recirculation Charcoal adsorber	None	
Costs	(365/364)	(147/147)	(0/709)	(0/1036)	(0/0)	(512/2256)
Case 5	Catalytic recombiner 30 min holdup, Charcoal delay system, 13-day Xe, 18-hr Kr	Clean steam	Charcoal adsorber	No treatment	100 meter	
Costs	(365/364)	(147/147)	(0/709)	(0/0)	(100/574)	(612/1794)
Case 6	Catalytic recombiner 30 min holdup, Charcoal delay system, 52-day Xe, 3-day Kr	Clean steam	Charcoal adsorber	Clean steam on valves 2-1/2" dia.and larger	None	
Costs	(355/355)	(147/147)	(0/709)	(0/387)	(0/0)	(502/1598)
Case 7	Catalytic recombiner 30 min holdup, Cryogenic distillation 90 day holdup tank	Clean steam	Charcoal adsorber	Clean steam on valves 2-1/2" dia.and larger Internal recirculation, Charcoal adsorber	None	
Costs	(914/355)	(147/147)	(0/709)	(0/1036)	(0/0)	(1061/2247)

* Source : Ref 3-29; costs in 1978 dollars for ($ thousands for noble gases/$ thousands for iodines).


11621* REFLECTOR BLOCKS
13751 1M BLOCKS
13941 23R BLOCKS
1311 25R BLOCKS
REACTOR CORE
* EQUIVALENT 31-in LONG BLOCKS
STORAGE VAULT AT REPROC PLANT
REFLECTOR BLOCKS
1M BLOCKS
23 R BLOCKS
25 R BLOCKS
FIX IN CONCRETE
PRIMARY BURNING
PRIMARY BURNING
PRIMARY BURNING
STACK FILTERS
IODINE REMOVAL
BURNER OFF GAS
20 MIN HOLDUP
PARTICLE SEPARATION, THOREX LEACH, WASH, DRY
PARTICLE SEPARATION, THOREX LEACH, WASH, DRY
PARTICLE SEPARATION, THOREX LEACH, WASH, DRY
UC_2
UC_2
UC_2 PARTICLES
CRACK SiC SECONDARY BURNING
CRACK SiC SECONDARY BURNING
UO_2
UO_2
25 R URANIUM STORAGE
ThO_2 + LEACH SOLN'S
ThO_2 + LEACH SOLN'S
ThO_2 + LEACH SOLN'S
DISSOLVE PUREX SX
DISSOLVE ACID-THOREX SX
THORIUM STORAGE
WASTE TREATMENT AND STORAGE
U FOR 23 R STREAM
U FOR 23 R STREAM
FUEL REFAB PLANT
23R AND 25R BLOCKS TO REACTOR

SUMMARY DIAGRAM OF FUEL FLOW IN THE HTGR CYCLE

Source: Reference 3-53

FIGURE 3.24

to a total exposure of 95,000 MWd/MTHM. The spent fuel is assumed to be cooled (decayed) for a minimum of 160 days before reprocessing. A summary diagram of the process is presented in Figure 3.24.

The plant processes three types of graphite fuel which, when charged to the reactor, contain in addition to the fertile ^{232}Th, (1) 93% ^{235}U (IM elements), (2) uranium recovered from spent IM elements and repurified for recycle (25R elements), and (3) ^{233}U bred from the fertile ^{232}Th (23R elements) (3-53). The model HTGR reprocessing plant would be significantly larger than a model LWR fuel reprocessing plant because of the need for a large graphite burning area as well as two solvent extractions systems, namely the Acid-Thorex and Purex systems.

A fuel storage facility capable of handling up to 15,000 fuel elements cooled for 160 days would be a part of the plant. The heat generation from this magnitude of spent elements could be as great as 300,000 BTU per minute. Leaking fuel elements would be individually handled and the off-gas processed through the plant gaseous treatment system. Cooling air (flow rate of about 600,000 cfm) would be passed through roughing and HEPA filters.

The initial steps in HTGR fuel reprocessing would be crushing the graphite fuel blocks into particles less than (3/16) inches in diameter and burning the particles in a fluidized bed reactor. The material would include fertile thorium particles (0.820 mm), fissile ^{235}U particles (0.540 mm) and fissile ^{233}U particles. The fuel element crushing would be accomplished by two overhead eccentric jaw crushers and a double roll crusher. Residuals from the primary burner would be transferred to a secondary burner where tritium would be baked out of the ThO_2. These operations would result in the release of radioactive gases such as tritium in the water vapor, ^{14}C in the carbon dioxide, noble gases, radioiodines, and ^{75}Se. Additionally, radioactive particulates would include quantities

TABLE 3-23

Capital and Annual Costs (1978 dollars) in Addition to the Base Case for Airborne Effluent Control Technologies at a Model LWR Reprocessing Plant*

Case and Description	Capital Cost ($1000)	Annual Cost ($1000)
Case 4 : Base Case plus sand filters in series with HEPA filters resulting in an additional decontamination factor of 10 for semi-volatiles, U, Pu, and particulates.(see Table 3-22).	1554	445
Case 5 : Base Case plus caustic scrubbers in series with acid scrubbers and HEPA filters resulting in an additional decontamination factor of 10 for semi-volatile radionuclides (see Table 3-22).	499	180

---

* Source : Ref 3-57; Base Case costs are not specified in (3-57); 1978 dollars were obtained from 1973 dollars given in (3-57) by multiplying with a factor of 1.467 based upon the Consumer Price Index listing.

90% removal efficiency for semi-volatile fission products (ruthenium) in the dissolver and vessel off-gas.

The residuals from the mercuric nitrate-nitric acid scrubber are estimated to be about 3 lbs/day of sodium iodate. The residuals from the other systems are not specifed in (3-51).

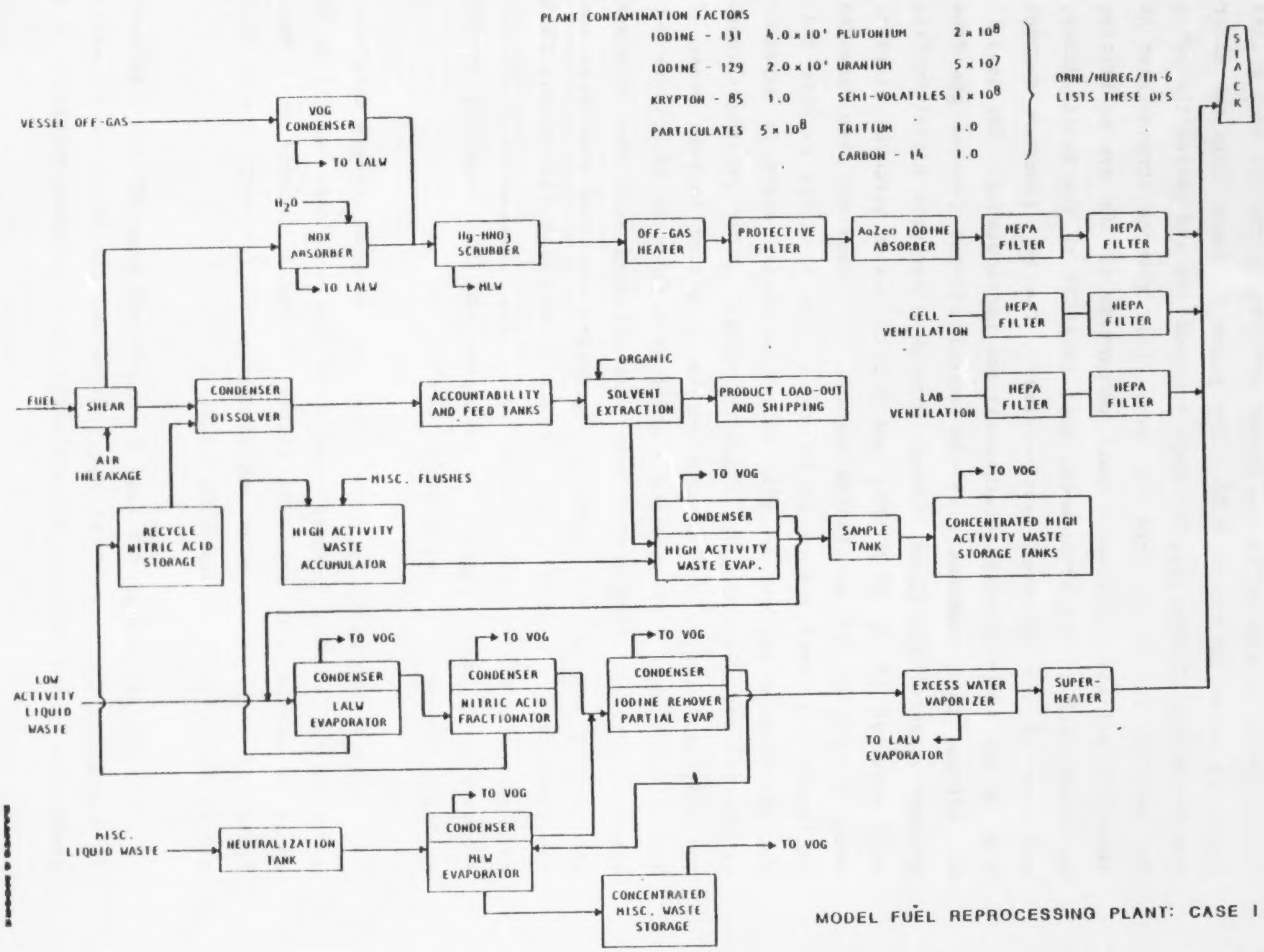
The same control technologies would apply for reprocessing of mixed oxide fuels since the processes described are effective for both uranium and plutonium.

The capital and annual costs of the airborne emission control technologies of the base case (Case 1) are not given in (3-57). However, the capital and annual costs in addition to the base case resulting from the improvements in the airborne emission control technologies are given for the other cases. These costs for Cases 4 and 7 described above and the total plant decontamination factors achieved with each system are given in Table 3-23.

HTGR Fuel Reprocessing Facilities

Reprocessing of HTGR fuel entails the recovery of both bred ^{233}U and residual uranium enriched in ^{235}U and isolation of the depleted uranium, plutonium, thorium, transuranics, and radioactive waste products in order to prepare them for storage or disposal. HTGR reprocessing plants are not in commercial use at the present time.

A model HTGR processing plant has been described and a cost-benefit study of radioactive waste treatment technologies has been performed by the Environmental Sciences Division of the Oak Ridge National Laboratory (ORNL/NUREG/TM-4) (3-53). The model HTGR reprocessing plant processes 450 metric tons of heavy metal per year (MTHM/yr) irradiated at an average specific power of about 64 MW/MTHM


PLANT CONTAMINATION FACTORS
IODINE - 131 4.0 x 10' PLUTONIUM 2 x 10^8
IODINE - 129 2.0 x 10' URANIUM 5 x 10^7
KRYPTON - 85 1.0 SEMI-VOLATILES 1 x 10^8
PARTICULATES 5 x 10^8 TRITIUM 1.0
CARBON - 14 1.0
ORNL/NUREG/TM-6 LISTS THESE DFS
VESSEL OFF-GAS
VOG CONDENSER
TO LALW
H2O
NOX ABSORBER
TO LALW
Hg-HNO3 SCRUBBER
HLW
OFF-GAS HEATER
PROTECTIVE FILTER
AgZeo IODINE ABSORBER
HEPA FILTER
HEPA FILTER
STACK
CELL VENTILATION
HEPA FILTER
HEPA FILTER
LAB VENTILATION
HEPA FILTER
HEPA FILTER
FUEL
SHEAR
AIR INLEAKAGE
CONDENSER
DISSOLVER
ACCOUNTABILITY AND FEED TANKS
ORGANIC
SOLVENT EXTRACTION
PRODUCT LOAD-OUT AND SHIPPING
RECYCLE NITRIC ACID STORAGE
MISC. FLUSHES
HIGH ACTIVITY WASTE ACCUMULATOR
TO VOG
CONDENSER
HIGH ACTIVITY WASTE EVAP.
SAMPLE TANK
TO VOG
CONCENTRATED HIGH ACTIVITY WASTE STORAGE TANKS
LOW ACTIVITY LIQUID WASTE
TO VOG
CONDENSER
LALW EVAPORATOR
TO VOG
CONDENSER
NITRIC ACID FRACTIONATOR
TO VOG
CONDENSER
IODINE REMOVER PARTIAL EVAP
EXCESS WATER VAPORIZER
TO LALW EVAPORATOR
SUPER-HEATER
MISC. LIQUID WASTE
NEUTRALIZATION TANK
TO VOG
CONDENSER
HLW EVAPORATOR
CONCENTRATED MISC. WASTE STORAGE
TO VOG

MODEL FUEL REPROCESSING PLANT: CASE I

DAMES & MOORE

FIGURE 3.23

The base case (Case 1) of airborne effluents and control technology, which is similar to the system utilized in the NFS West Valley Plant, is shown in Figure 3.23. The gaseous streams from the shear (chop) and dissolution (leach) steps are combined and passed through a NO_x absorber for nitric acid recovery. This gaseous stream known as dissolver off-gas contains a small percentage of the system tritium inventory, all of the krypton-85, more than 75% of the radioiodines, and some of the expected particulates. The NO_x absorber removes some of the semi-volatiles (ruthenium) and particulates. The dissolver off-gas then combines with the vessel off-gas (vented gas from process vessels) and flows through through a mercuric nitrate-nitric acid scrubber (8 to 10 M HNO_3 and 0.2 to 0.4 M mercuric nitrate) where 90% removal of radioiodine occurs. The gases are then reheated and coarse filtered before introduction into a silver zeolite bed. The radioiodine removal in this silver molecular sieve is approximately 99% for elemental and organic iodine. After passing through the molecular sieve, the gaseous stream is passed through banks of HEPA filters with a particulate removal efficiency of 99.95% for 0.3 micron particles. These HEPA banks are designed such that in-place DOP testing can be performed. Ventilation air from the cells and laboratories is passed first through a roughing filter and then through a HEPA filter bank (Figure 3-23). The decontamination factors achieved with these control technologies and the resulting annual emissions are shown in Table 3-22.

Control technology for Case 4 involves the same off-gas treatment as described for Case 1 except that a 30 inch deep sand bed filter is added in series with the HEPA filters. The efficiency of a sand filter of this magnitude is approximately 99% for particulates that are in the effluent of the HEPA filter.

Control technology for Case 5 employs the same off-gas treatment as described for Case 1 except that a caustic scrubber is added downstream of the mercuric nitrate-nitric acid scrubber resulting in a

TABLE 3-22

Average Fuel Activity and Release Rates at a Model LWR Reprocessing Plant*

	Nuclide	Initial Activity** (Ci/MTU)	DF***	Release Rate (Ci/yr)
Volatiles	H-3	5.14E+2****	1	7.7E+5
	C-14	5.54E-1	1	8.3E+2
	Kr-85	9.26E+3	1	1.4E+7
	I-129	3.33E-2	20	2.5E+0
	I-131	9.23E-1	40	3.5E+1
Semi Volatiles	Ru-103	8.74E+4	1E+8	1.3E+0
	Ru-106	3.80E+5	1E+8	5.7E+0
Uranium	U-234	7.55E-1	5E+7	2.3E-5
	U-235	1.71E-2	5E+7	5.1E-7
	U-236	2.88E-1	5E+7	8.6E-6
	U-238	3.14E-1	5E+7	9.4E-6
Plutonium	Pu-238	2.82E+3	2E+8	2.1E-2
	Pu-239	3.23E+2	2E+8	2.4E-3
	Pu-240	4.75E+2	2E+8	3.6E-3
	Pu-241	1.02E+5	2E+8	1.7E-1
	Pu-242	1.37E+0	2E+8	1.0E-5
Parti-culates	Sr-89	8.51E+4	5E+8	2.6E-1
	Sr-90	7.68E+4	5E+8	2.3E-1
	Y-90	7.68E+4	5E+8	2.3E-1
	Y-91	1.43E+5	5E+8	4.3E-1
	Zr-95	2.54E+5	5E+8	7.6E-1
	Nb-95	4.73E+5	5E+8	1.4E+0
	Ag-110m	2.38E+3	5E+8	7.1E-3
	Sb-125	7.89E+3	5E+8	2.4E-2
	Te-127m	5.08E+3	5E+8	1.5E-2
	Te-129m	2.74E+3	5E+8	8.2E-3
	Cs-134	2.21E+3	5E+8	6.6E-1
	Cs-137	1.07E+5	5E+8	3.2E-1
	Ce-141	4.56E+4	5E+8	1.4E-1
	Ce-144	7.36E+5	5E+8	2.2E+0
	Pm-147	9.42E+4	5E+8	2.8E-1
	Eu-154	1.17E+4	5E+8	3.5E-2
	Eu-155	2.44E+3	5E+8	7.9E-3
	Am-241	1.58E+2	5E+8	4.7E-4
	Am-243	1.80E+1	5E+8	5.4E-5
	Cm-242	1.69E+4	5E+8	5.1E-2
	Cm-244	2.38E+3	5E+8	7.1E-3

---

* Source : Ref 3-57. The model plant processes 1,500 MTU/year.

** The fuel is irradiated to 33,000 MWd/MTU and decayed for 160 days.

*** Total decontamination factor for "Case 1" control technologies.

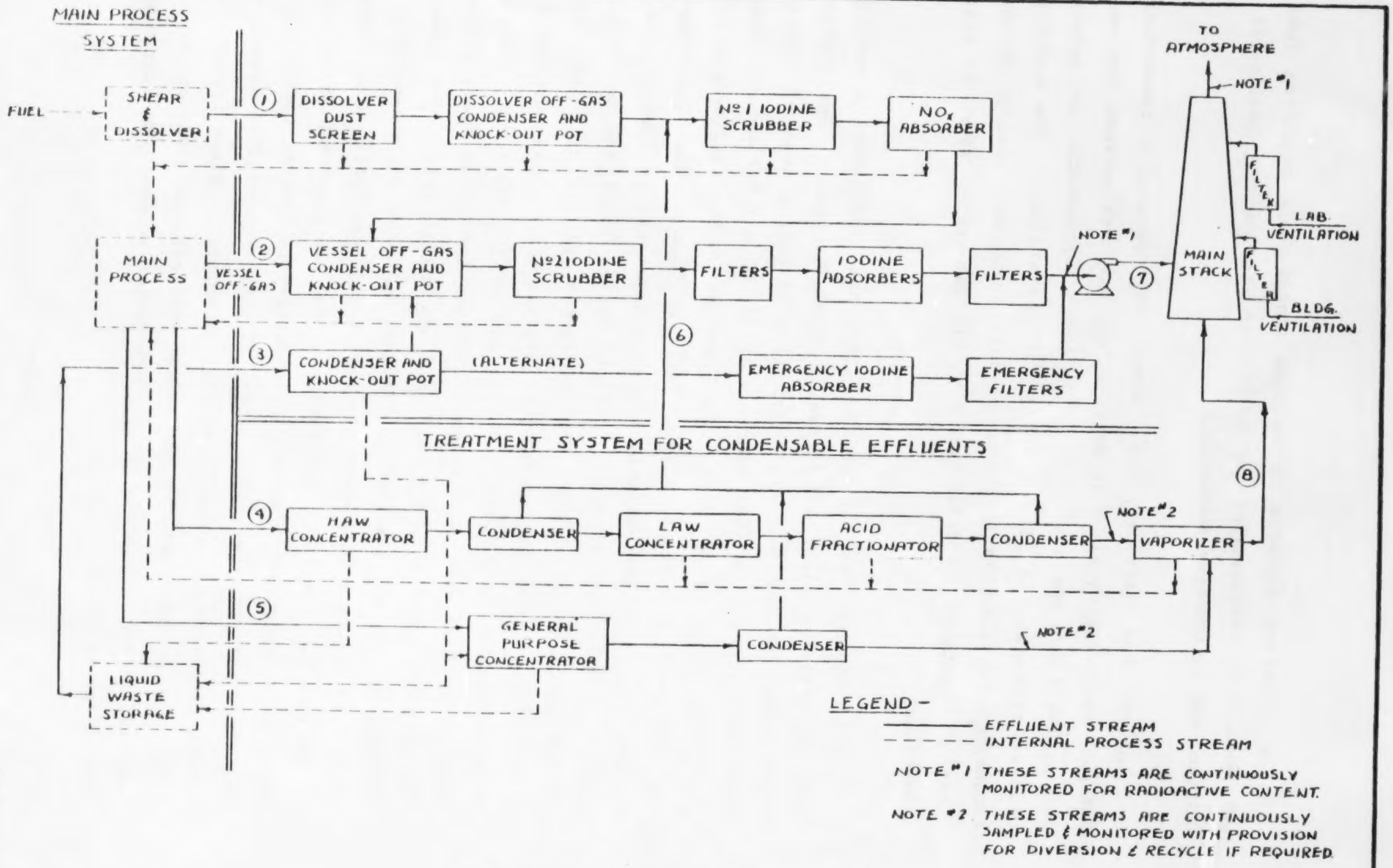
****Exponential notation, e.g., 5.14E+2 = 5.14×10^2.

The expected effluent release rates from the Barnwell Plant include tritium at 0.018 Curies per second (Ci/sec), krypton-85 at 0.42 Ci/sec, ruthenium-106 at 0.05 uCi/sec, strontium-90 at 8.8 nCi/sec, cesium-137 at 12 nCi/ sec, plutonium-238 at 0.13 nCi/sec, plutonium-239 at 0.012 nCi/sec, and 5.5 nCi/sec of plutonium-241 (3-52). These release rates are based on decontamination factors of one for tritium and krypton-85, 1000 for radioiodines, and a particulate removal efficiency of 99.8% for particles greater than 0.3 microns. Data on capital costs, annual operating costs, and expected residuals are not available.

Recent cost-benefit studies (3-51, 3-57) of radioactive waste treatment systems for LWR fuel reprocessing plants were performed by the Environmental Sciences Division of the Oak Ridge National Laboratory. In these studies, a model plant equipped with currently available exemplary control technology is described and the costs and resulting dose commitment are delineated. Additional cost and dose data are presented for cases where additional waste treatment technologies have been added. A summary of the results of these studies is presented below.

The model LWR fuel reprocessing plant processes 1500 metric-tons uranium (MTU) per year which has been irradiated at an average specific power of 30 Megawatts per MTU and an exposure of 33,000 Megawatt-days per MTU. The fuel has been decayed at least 160 days before it is processed by the Purex process (described above). The major radioactive constituents in the feed to the plant which could be released in the gaseous effluent are shown in Table 3-22.

Several cases each involving different airborne emission control technologies are considered in reference 3-57 for the same model plant. The cases denoted by "Case 1", "Case 4" and "Case 5" are considered below. Other cases considered involve advanced technologies that have not been demonstrated, and these cases are discussed in later sections.


MAIN PROCESS SYSTEM
FUEL
SHEAR & DISSOLVER
MAIN PROCESS
VESSEL OFF-GAS
LIQUID WASTE STORAGE
①
DISSOLVER DUST SCREEN
DISSOLVER OFF-GAS CONDENSER AND KNOCK-OUT POT
Nº1 IODINE SCRUBBER
NO$_x$ ABSORBER
②
VESSEL OFF-GAS CONDENSER AND KNOCK-OUT POT
Nº2 IODINE SCRUBBER
FILTERS
IODINE ADSORBERS
FILTERS
NOTE #1
⑦
③
CONDENSER AND KNOCK-OUT POT
(ALTERNATE)
⑥
EMERGENCY IODINE ABSORBER
EMERGENCY FILTERS
TO ATMOSPHERE
NOTE #1
MAIN STACK
FILTER
LAB. VENTILATION
FILTER
BLDG. VENTILATION
TREATMENT SYSTEM FOR CONDENSABLE EFFLUENTS
④
HAW CONCENTRATOR
CONDENSER
LAW CONCENTRATOR
ACID FRACTIONATOR
CONDENSER
NOTE #2
VAPORIZER
⑧
⑤
GENERAL PURPOSE CONCENTRATOR
CONDENSER
NOTE #2
LEGEND -
EFFLUENT STREAM
INTERNAL PROCESS STREAM
NOTE #1 THESE STREAMS ARE CONTINUOUSLY MONITORED FOR RADIOACTIVE CONTENT.
NOTE #2 THESE STREAMS ARE CONTINUOUSLY SAMPLED & MONITORED WITH PROVISION FOR DIVERSION & RECYCLE IF REQUIRED.

BARNWELL NUCLEAR

Source: Reference 3-52

FIGURE 3.22

The principal airborne radioactive contaminants resulting from LWR spent fuel reprocessing are krypton-85, iodine-131, iodine-129, tritium, and radioactive particulates.

Nuclear Fuel Services, Inc., owned and operated a commercial LWR fuel reprocessing plant at West Valley, New York between 1966 and 1972. The plant was shut down in 1972 for improvements and safety related reasons. It is currently not operational. The control technology for airborne effluents of this plant were similar to the "Case 1" described in reference 3-51 and summarized later in this subsection.

Allied-General Nuclear Services Inc. has constructed a nuclear fuel reprocessing plant at Barnwell, South Carolina. The process design rate for the Barnwell Plant is 1500 metric tons of uranium (MTU) per year with a fuel exposure of 32,000 MWd/MTU and a minimum fuel decay period of 180 days. The "non-condensable" effluent treatment system of this plant is illustrated in Figure 3.22. The process off-gas system at the Barnwell Plant includes two related treatment systems, namely the dissolver off-gas system (DOG) and the vessel off-gas system (VOG) (3-52). The DOG system consists of a condenser, a vapor-liquid separator, a mercuric nitrate-nitric acid scrubber for radioiodine and particulate removal, and an NO_x absorber. The NO_x absorber is five feet in diameter, contains twenty-two trays and has 70% recovery capability for NO_x as a 45% nitric acid. The gaseous effluent of the NO_x absorber is combined with the VOG stream at this point (see Figure 3-20), since its radioiodine and nitric acid content is reduced to relatively low levels. The VOG treatment system consists of a condenser, a vapor-liquid separator, another iodine scrubber (mercuric nitrate-nitric acid), filters (unspecified type), and iodine absorbers (presumably charcoal or molecular sieve types). Air flow through the plant is controlled by pressure zonation and all ventilation air is passed through HEPA filter systems just upstream of the 100 meter stack.

Fuel Reprocessing Facilities

The last step in the closed-loop nuclear fuel cycle is fuel reprocessing. There are no operational commercial fuel reprocessing facilities in the United States today. However, Nuclear Fuel Services operated a facility until 1972 at West Valley, NY, a facility was built by General Electric at Morris, Illinois but never operated, and a third facility has been constructed by Allied-General Nuclear Services at Barnwell, SC. The control technologies for airborne effluents from reprocessing of irradiated LWR fuel and HTGR fuel are discussed below.

LWR Fuel Reprocessing Facilities

Reprocessing of LWR fuel entails the recovery of the fissile material from spent (irradiated) fuels. The process is designed to recover and purify the spent but still enriched uranium (containing about 1 to 2 atom percent of ^{235}U) and the produced ^{239}Pu for reuse in making new reactor fuel.

The initial step of reprocessing is the chop-leach process. The spent fuel rods are introduced remotely into a process mechanical cell where the rods are chopped into relatively small pieces. The chopped fuel fragments are remotely introduced into a fuel dissolver where nitric acid is employed to dissolve the fuel away from zircaloy or stainless steel fuel cladding. The dissolved spent fuel material undergoes a series of solvent extraction steps to recover and purify the uranium and plutonium. The reusable uranium and plutonium are extracted from the aqueous feed by an organic solvent (usually tributyl phosphate dissolved in kerosene or dodecane) while the fission product waste remains in the aqueous acid phase. The plutonium and uranium are separated from each other and exit the extraction system as aqueous solutions which are subjected to further purification and processing before packaging and shipment.

primary types of radionuclides present in Fermi I waste gas were argon-41 and fission gases, with small amounts of tritium and carbon-14 also being produced by reactor operation (3-50). All waste gases flowed through a common waste header and through a particulate filter. The major portion of the gases fed through the header originated either from the reactor primary system or the fuel handling and decay system. Upon passage through the filter the activity of the gas was measured. The gases were either diverted to storage tanks for radionuclide decay or sent directly to the stack inlet depending upon the gas activity. The primary inert gas system discharge and the cleaning gas discharge from the Fuel and Repair Building were expected to require decay time before release. A holdup time of 45 days was available from each of the two holdup tanks in parallel. Gases released from the holdup tanks passed through an "absolute" (HEPA) filter (3-50).

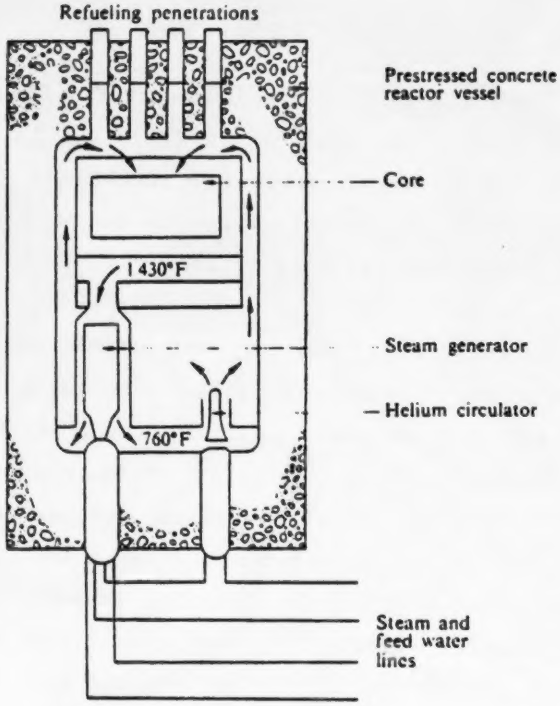
The exemplary control technologies for airborne effluents associated with reactors other than LWRs cannot be determined based on the available information. However, it probably will involve holdup tanks and/or delay systems for noble gases, charcoal delay systems or cryogenic distillation procedures for halogens (radioiodine), and particulate filter systems which include HEPA filters for the airborne particulates.

There are no fast breeder reactors (FBRs) operating in the United States today. An application (docketed in 1975) for a construction permit for a liquid metal FBR (LMFBR) in Clinch River in Tennessee is presently pending (3-44). The Fermi I FBR in Michigan was scheduled for decommissioning in 1972 (3-48).

A fast breeder reactor, which does not utilize a moderator, uses a uranium-plutonium fuel cycle. The reactor may initially be fueled with enriched uranium. However, the fissile plutonium isotopes which are produced during operation ultimately replace the ^{235}U, and the system then operates on plutonium isotopes and natural and/or depleted uranium (3-45). A schematic diagram of an FBR steam supply system is shown in Figure 3-21. Sodium is used as the coolant and as the heat transfer agent. The reactor in Figure 3-21 has two sodium loops: one primary loop which is in contact with the core, and a secondary loop which receives heat from the primary loop and is then utilized to generate steam.

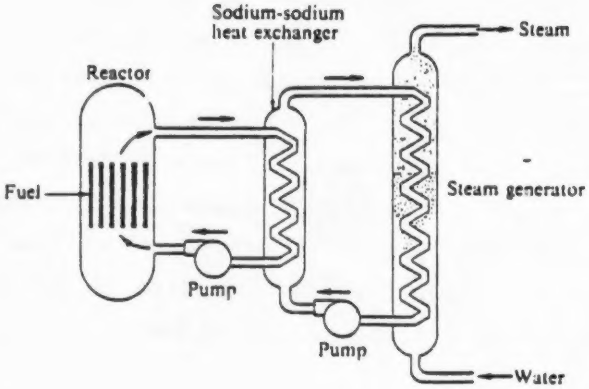
The control technology for airborne radioactive effluents for the Clinch River LMFBR will consist of the Radioactive Argon Processing Subsystem (RAPS) and the Cell Atmosphere Processing Subsystem (CAPS) (3-49). Cover gas from the reactor and primary heat transfer system are decontaminated and recycled by the RAPS. For removal of radioactive gases, it will contain four cryogenic charcoal delay beds in series followed by a cryogenic distillation system. Separated radioactive noble gases will also be held in storage for decay prior to disposal. The independently operated CAPS will decontaminate gas that may result from minute leakage from systems containing potentially radioactive gas. For removal of radioactive gases the CAPS will contain an oxidation process system for tritium removal followed by two cryogenic charcoal beds in series.

A discussion of the preliminary design of the gasesous waste system of the Fermi I fast breeder reactor is given in (3-29). The


Refueling penetrations
Prestressed concrete reactor vessel
Core
1 430°F
Steam generator
Helium circulator
760°F
Steam and feed water lines

SCHEMATIC OF HTGR

Source: Reference 3-45


Sodium-sodium heat exchanger
Steam
Reactor
Fuel
Steam generator
Pump
Pump
Water

SCHEMATIC OF LMFBR STEAM SUPPLY SYSTEM

Source: Reference 3-45

Other Central Station Nuclear Power Plants

This subsection considers the airborne emission control technology utilized in central station nuclear power plants other than LWRs. Two major types of plants are considered: high temperature gas cooled reactors (HTGRs) and fast breeder reactors (FBRs).

The Fort Saint Vrain plant in Colorado is the only HTGR operating in the United States today. The Peach Bottom 1 HTGR in Pennsylvania was shut down in 1974, and, as of May 1978, there are no construction permits in effect for any HTGRs (3-44).

Fort Saint Vrain HTGR is graphite moderated, helium cooled, and requires fuel enriched in uranium-235 (see Figure 3-20). Helium coolant flows downward through the core and through the steam generators, where its heat is transferred to a water stream to produce steam. The helium is pumped back to the core through circulation blowers (3-45). Fission products rather than activation products are the primary source of airborne radionuclides at Fort Saint Vrain. Noble gas radionuclides predominate in gaseous effluent releases. Most of the gaseous radioiodine is plated out internally (3-46).

Routine sources of gaseous waste of radiological significance at Fort Saint Vrain are: (1) the helium purification system, (2) instrument effluent, (3) fuel handling purge system vacuum pumps, (4) the fuel storage facility, and (5) core support floor vent (3-47). All potentially radioactive gases are handled by the gaseous radwaste system which consists of a vacuum tank and two holdup tanks (3-46). Gas discharged after holdup is successively channeled through a mist eliminator, pre-filter, HEPA filter, and charcoal prior to stack. Samples of the charcoal air are extracted periodically and checked for the efficiency of methyl iodide removal. The charcoal on line is maintained for a removal efficiency of greater than 90% for methyl iodide. The holdup tank(s) is discharged several times per month (3-46).

For the primary coolant gases, the use of a catalytic recombiner-charcoal delay system with pressurized storage tanks such that a total holdup time of 60 days for Xe and 31 days for Kr is achieved (Case 5) reduces noble gas releases only 7% lower than those from 45 day holdup tank system. However, almost complete removal of radioiodines is achieved with the recombiner-charcoal delay system (3-29). Catalytic recombiner-pressurized delay tank systems are being designed for the current generation of PWRs and a catalytic recombiner-cryogenic charcoal adsorbtion system (similar to Case 6) is presently employed at San Onofre 1 (3-38). In these systems, excess hydrogen is recombined with oxygen to form water vapor which is later removed from the system. Noble gases and iodine are liquified and then either put through a charcoal delay system or separated by distillation in the cryogenic distillation system (3-29). Noble gas and iodine decay, with the exception of Kr-85 (half life approximately 10.8 years), is almost complete for these model cases.

The exemplary control technology for airborne radionuclides in the primary coolant gases appears to be the catalytic recombiner-pressurized holdup tank systems in the cases considered. The addition of filter systems in series with this system must be evaluated on a case-by-case basis, since from the model cases (see Table 3-21) it appears that a cost-benefit study of the filter system may be necessary. The exemplary control technology for other sources that must be controlled in order to satisfy the applicable criteria appears to be filter systems consisting of prefilters, HEPA filters, and charcoal adsorbers in some combination.

TABLE 3-21 : Summary of Annual Costs Applicable to Control of Noble Gases and Iodine Emissions from 2400 MW(e) PWR stations*

Cases	Primary System	Condenser Air Ejector	Steam Generator Blowdown tank	Internal Cleanup	Purge Vent	Aux. Bldg. Ventilation	Turb. Bldg Ventilation	Stack	Totals
Case 1	7-day holdup PST, HEPA filters	No treatment	Vent to atmosphere	No treatment	No treat ment	No treatment	No treatment	None	
Costs	(198/0)	(0/0)	(0/0)	(0/0)	(0/0)	(0/0)	(0/0)	(0/0)	(198/0)
Case 2	45-day holdup PST, HEPA filters	No treatment	Vent thru condenser	4,000 cfm Ch.adsorber	No treatment	No treatment	No treatment	None	
Costs	(217/0)	(0/0)	(0/16)	(0/29)	(0/0)	(0/0)	(0/0)	(0/0)	(217/45)
Case 3	45-day holdup PST, HEPA filters	Charcoal adsorber	Vent thru condenser	20,000 cfm Ch.adsorber	No treatment	Charcoal adsorber	No treatment	None	
Costs	(217/0)	(0/79)	(0/16)	(0/119)	(0/0)	(0/282)	(0/0)	(0/0)	(217/496)
Case 4	60-day holdup PST, HEPA filters	Charcoal adsorber	Vent thru condenser	20,000 cfm Ch.adsorber	Charcoal adsorber	Charcoal adsorber	Clean steam on valves 2-1/2" dia.or larger	None	
Costs	(239/0)	(0/79)	(0/16)	(0/119)	(0/156)	(0/282)	(0/406)	(0/0)	(100/1058)
Case 5	Catalytic recombiner, Charcoal delay system, PST 60 days Xe, 31 days Kr	Charcoal adsorber	Vent thru condenser	20,000 cfm Ch.adsorber	Charcoal adsorber	Charcoal adsorber	No treatment	None	
Costs	(195/0)	(0/79)	(0/16)	(0/119)	(0/156)	(0/282)	(0/0)	(0/0)	(100/651)
Case 6	Catalytic recombiner Cryogenic distillation 90-day holdup PST	Charcoal adsorber	Vent to condenser	No treatment	Charcoal adsorber	Charcoal adsorber	No treatment	None	
Costs	(192/0)	(0/79)	(0/9)	(0/0)	(0/156)	(0/282)	(0/0)	(0/0)	(100/525)
Case 7	45-day holdup PST, HEPA filters	No treatment	No blowdown	20,000 cfm Ch.adsorber	Charcoal adsorber	Charcoal adsorber	No treatment	None	
Costs	(217/0)	(0/0)	(0/0)	(0/119)	(0/156)	(0/282)	(0/0)	(0/0)	(100/556)
Case 8	Cover gas recycle, 90-day holdup PST	Charcoal adsorber	Heat exchanger, Blowdown tank, Ion Exchange	20,000 cfm Ch.adsorber	Charcoal adsorber	Charcoal adsorber	No treatment	None	
Costs	(516/0)	(0/79)	(0/21)	(0/119)	(0/156)	(0/282)	(0/0)	(0/0)	(100/656)
Case 9	60-day holdup PST, HEPA filters	Charcoal adsorber	Vent thru condenser	20,000 cfm Ch.adsorber	Charcoal adsorber	Charcoal adsorber	Charcoal adsorber	100 meter	
Costs	(239/0)	(0/79)	(0/16)	(0/119)	(0/156)	(0/282)	(0/734)	(257/257)	(496/1642)

* Source : Ref 3-29; costs in 1978 dollars for ($ thousands for noble gases/$ thousands for iodines); PST : Pressurized storage tank.

TABLE 3-20

Summary of Control Technologies for PWRs Considered

System	Indian Point 2 (1)	Zion 1 and 2 (2)	Rancho Seco (3)	Seabrook 1 & 2 (4)
Primary Coolant Gases	45-day holdup tanks	45-day holdup tanks	45-day holdup tanks; PHC filter system	Holdup tanks; HEPA filter
Condenser Air Ejector Off-Gas	No treatment	No treatment	PHC filter system (5)	HEPA and charcoal filters in series
Steam Generator Blowdown Tank Air	No treatment	No treatment		Vented through the condenser system
Containment Purge Air	PHC filter system	No treatment	PHC filter system	HEPA and charcoal filters in series
Auxiliary Bldg Ventilation Air	No treatment	No treatment	PHC filter system	HEPA and charcoal filters in series
Turbine Bldg Ventilation Air	No treatment	No treatment	No treatment	No treatment

---

(1) Ref 3-39; Indian Point 2, Westchester Co. NY, Consolidated Edison Co. of NY.; Operational PWR; Authorized for 873 MW(e); First Criticality : May 1973.

(2) Refs 3-38, 3-40, 3-41; Zion 1 & 2, Lake Co., Ill., Commonwealth Edison Co.; Operational PWRs; Each authorized for 1040 MW(e); First Criticality : Unit 1 in June 1973, Unit 2 in December 1973.

(3) Ref 3-43; Rancho Seco, Sacramento Municipal Utility District, California; Operational PWR; Authorized for 852 MW(e); First Criticality : September 1974.

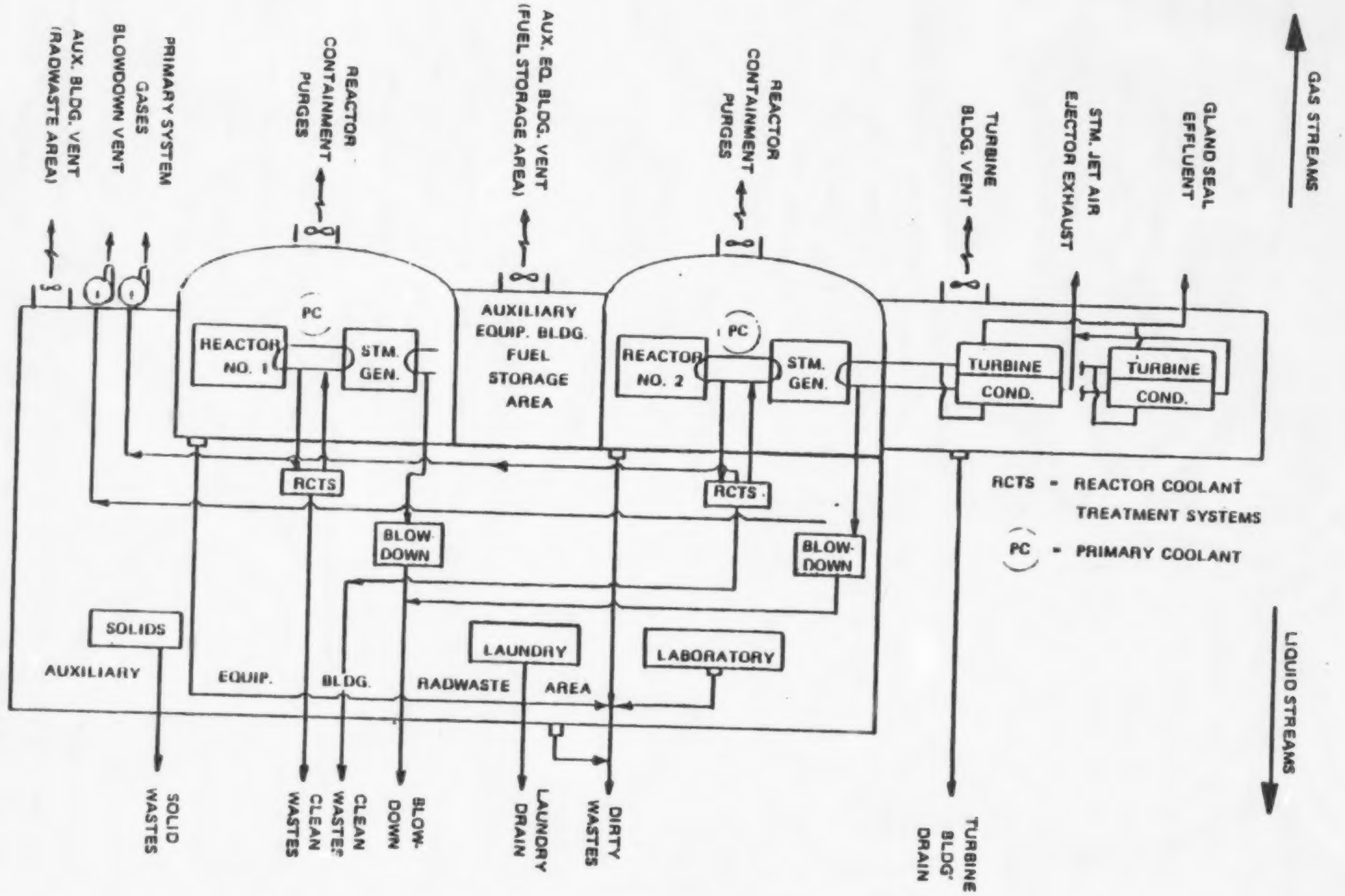
(4) Ref 3-42; Seabrook 1 & 2, Rockingham Co. New Hampshire, Public Service Co. of New Hampshire; Under construction; Design power level for each authorized 1200 MW(e).

(5) PHC filter system is composed of a prefilter (manufacturer efficiency of 50%), a HEPA filter (manufacturer efficiency of 99.97% for particles greater than 0.3 um), and a charcoal filter (efficiency estimated 99%). For systems that do not include one or more of these components, i.e., specific reference to the component could not be located, the efficiencies individual components are applicable separately.

operations is primary coolant leakages. Gaseous wastes released by building ventilation systems can be gases from primary coolant leaks in the reactor containment and auxiliary buildings. The auxiliary building contains the radioactive waste treatment equipment and vents the fuel storage pool. The turbine building ventilation may vent radioactive gaseous effluent from steam leakage. The control technologies for the PWRs examined in detail are summarized in Table 3-20.

For the primary coolant gases, pressurized holdup tanks are utilized at most of the PWRs that are operational or under construction (3-38). The PWRs examined have holdup tanks designed for 45 day delay (3-39 through 3-43). After holdup, gases are released directly to the stack without passing through a HEPA filter or a particulate filter system at the Indian Point 2, and Zion Units (3-39 and 3-40), and are passed through filter systems at the other two PWRs (3-42 and 3-43). Some of the other potential sources of airborne radioactivity in the PWRs examined have particulate filter systems, including HEPA filters (3-38 through 3-43).

Estimated annual costs for the control of radioactive effluents from the normal operations of a model PWR power station, described above and shown in Figure 3.19, consisting of two 1200 MW(e) units and four steam generators with one turbine each are given in Table 3-21 (3-29). Nine cases employing a variation of control technologies are given. The annual cost for each control technology is the sum of the annual operational, maintenance and fixed charges on capital. They are given in terms of 1978 dollars obtained from early 1973 dollars given in (3-29) by multiplying with a factor of 1.467 based upon the Consumer Price Index listing. All of the types of treatment technologies employed, i.e., pressurized holdup tanks, catalytic recombiner-charcoal delay systems, individual charcoal adsorbers, use of clean steam on turbine valves, cryogenic distillation, particulate filter systems and HEPA filters, are currently used in power reactors.


GAS STREAMS
LIQUID STREAMS
GLAND SEAL EFFLUENT
STM. JET AIR EJECTOR EXHAUST
TURBINE BLDG. VENT
REACTOR CONTAINMENT PURGES
AUX. EQ. BLDG. VENT (FUEL STORAGE AREA)
REACTOR CONTAINMENT PURGES
PRIMARY SYSTEM GASES BLOWDOWN VENT
AUX. BLDG. VENT (RADWASTE AREA)
TURBINE
COND.
TURBINE
COND.
REACTOR NO. 2
STM. GEN.
PC
AUXILIARY EQUIP. BLDG. FUEL STORAGE AREA
REACTOR NO. 1
STM. GEN.
PC
RCTS
RCTS
BLOW-DOWN
BLOW-DOWN
SOLIDS
LAUNDRY
LABORATORY
AUXILIARY EQUIP. BLDG. RADWASTE AREA
RCTS - REACTOR COOLANT TREATMENT SYSTEMS
PC - PRIMARY COOLANT
TURBINE BLDG' DRAIN
DIRTY WASTES
LAUNDRY DRAIN
BLOW-DOWN
CLEAN WASTES
CLEAN WASTES
SOLID WASTES
DAMES & MOORE

LIQUID AND GASEOUS RADWASTE EFFLUENTS FROM PRESSURIZED WATER REACTORS

SOURCE: REFERENCE 5-29

FIGURE 3.19

Pressurized Water Reactors

In a pressurized water reactor, the heat from the fuel elements is removed by the primary cooling/moderating water circulating through the reactor core. This heat is transferred from the primary coolant to the secondary coolant water in the steam generator to form steam which expands through a turbine, is condensed, and is returned to the steam generators (3-29).

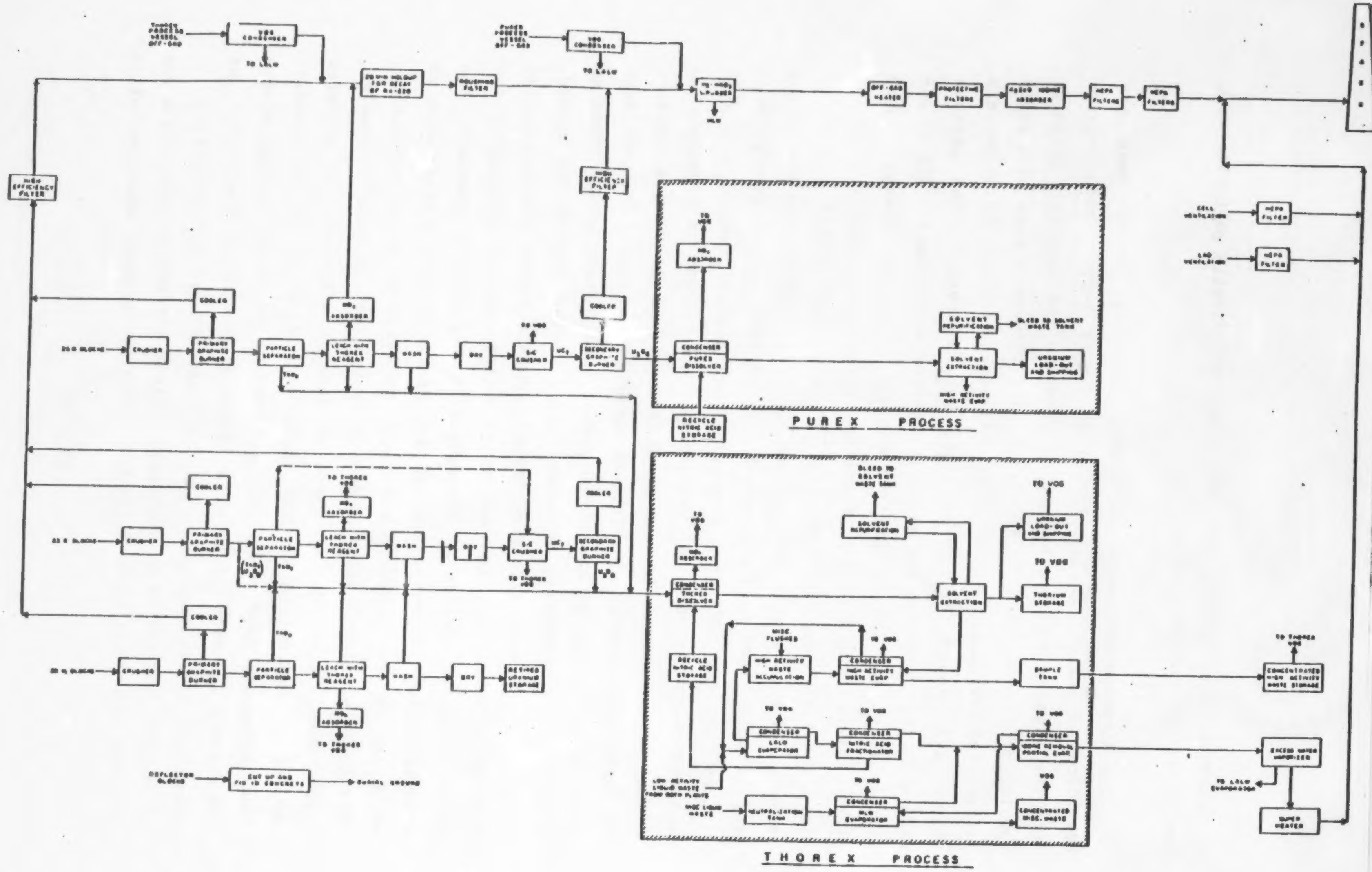
Both fission and activation gases are produced in PWRs. The discussion of the types of radionuclides formed and their genesis provided in the BWR section is also valid for PWRs. Between 1970 and 1974, the activity of gaseous effluents (noble gases and halogens) per GW(e)-year from BWRs were 20 times greater than those from PWRs, and the activity of particulates per GW(e)-year from BWRs were 4 times greater than those from PWRs (3-36). However, the activity of tritium in airborne releases per GW(e)-year during this time from PWRs was approximately a factor of 10 larger than from BWRs (3-36).

The major potential sources of gaseous and particulate radionuclides from a model nuclear station consisting of two 1200 MW(e) PWRs and four steam generators with one turbine each is shown in Figure 3.19 (3-29). Gaseous radionuclide effluent from such a station may be classified as being primary coolant, secondary coolant, and building ventilation gases (3-29). Primary coolant gases consist of gases stripped from the shim bleed (side coolant stream from which boron is removed) during normal operation, from the primary coolant during shutdown, and from the volume control tank used for the cover gas recycle. Secondary coolant gases include gases vented from the steam generator blowdown flash tank and from the steam jet air exhaust. The chemistry of the secondary coolant is controlled by discharging (blowing down) a portion of the secondary coolant to the steam generator blowdown flash tank (3-32). The only source of radioactivity for the secondary cooling system under routine and an additional factor of 10 for the charcoal delay system (3-29). The SJAE system in Case 6 provides essentially complete removal of radioiodine from the effluent (3-29). A charcoal adsorber is used in several cases to remove radioiodine from the ventilation air of buildings prior to release. Varying schemes for treating turbine building ventilation exhaust are also considered.

The exemplary control technology for noble gases and radioiodines in the steam-jet air ejector off-gas (SJAE system is normally the largest source of airborne radionuclides) on the basis of performance is the combination catalytic recombiner-low temperature charcoal delay system (Case 6 in Table 3-19). With regard to emission reduction, this system also appears to be more cost effective (on the basis of total common costs) than the next best control technology, the combination recombiner-ambient temperature charcoal delay system. The best control technology for radionuclide emission from the turbine gland seal exhaust (TGE) is the use of non-reactor generated steam to seal the turbine. However, this does not appear to be cost effective, nor exemplary, since it is 20 times more expensive than the system using nuclear steam with two-minute holding piping which appears to be sufficient to meet the necessary requirements. The exemplary control technology for the radioactive waste building ventilation air appears to be particulate filter systems including HEPA filters. The reactor and turbine building ventilation exhausts are generally much smaller sources of airborne radionuclide releases.

of contaminated graphite, ThO_2 particles, and fissile particles with broken silicon carbide coatings.

The airborne effluents and control technology for the base case considered in (3-53) is illustrated in Figure 3-25. The off-gases from the primary graphite burning process and the secondary graphite burning process for the (23R) stream pass through a high efficiency filter, and are joined by the vessel off-gases from the Thorex process which have passed through separate NO_x absorbers. The gaseous stream at this point in the process contains approximately 20% of the radioiodines, and all of the noble gases, ^{14}C, and tritium. This stream enters into a 20 minute holdup tank, which contains molecular sieve material, for the decay of ^{220}Rn which has a half life of 55 seconds. The stream is then joined by the off-gases from the secondary graphite burning (25R) stream, which have passed through HEPA filters, and the off-gases from the Purex process, which have also passed through separate NO_x absorbers. This stream is processed in a mercuric nitrate-nitric acid scrubber where 90% radioiodine recovery and comparable removal of tritiated water is realized. The tritiated water vapor is sent to the miscellaneous liquid waste stream where it is eventually discharged as water vapor. After leaving the $Hg-HNO_3$ scrubber the gaseous stream is heated, rough filtered and then passed through a silver zeolite bed where a 99% removal efficiency for radioiodines is achieved. Subsequent to the zeolite treatment, the gaseous stream is passed through two banks of HEPA filters each of which can be DOP tested in place and are rated at 99.95% efficiency. This implies a total decontamination factor (DF) of $4x10^6$. However, since some degree of impairment of removal efficiency is expected because of the nature of HEPA employment, a DF of 10^5 is assumed. Ventilation air from cells and laboratories are passed through roughing filters and HEPA filter banks before stack (100 m) discharge. The quantities of residuals from gaseous treatment are not available. It is assumed that the major residuals include dry sodium iodate from the scrubber and spent HEPA filters. The overall plant decontamination


THOREX PROCESS VESSEL OFF-GAS
VOG CONDENSER
TO LALW
30 DAY HOLDUP FOR DECAY OF Rn-220
POLISHING FILTER
PUREX PROCESS VESSEL OFF-GAS
VOG CONDENSER
TO LALW
NO-NO2 SCRUBBER
HLW
OFF-GAS HEATER
PROTECTIVE FILTERS
FIXED IODINE ABSORBER
HEPA FILTERS
HEPA FILTERS
CELL VENTILATION
HEPA FILTER
LAB VENTILATION
HEPA FILTER
HIGH EFFICIENCY FILTER
HIGH EFFICIENCY FILTER
COOLER
CRUSHER
PRIMARY GRAPHITE BURNER
PARTICLE SEPARATION
LEACH WITH THOREX REAGENT
NOx ABSORBER
WASH
DRY
SiC CRUSHER
TO VOG
UC2
SECONDARY GRAPHITE BURNER
U3O8
ThO2
CONDENSER
PUREX DISSOLVER
NOx ABSORBER
TO VOG
RECYCLE NITRIC ACID STORAGE
SOLVENT REPURIFICATION
BLEED TO SOLVENT WASTE TANK
SOLVENT EXTRACTION
URANIUM LOAD-OUT AND SHIPPING
HIGH ACTIVITY WASTE EVAP
PUREX PROCESS
TO THOREX VOG
RETIRED URANIUM STORAGE
REFLECTOR BLOCKS
CUT UP AND FIX IN CONCRETE
BURIAL GROUND
CONDENSER
THOREX DISSOLVER
RECYCLE NITRIC ACID STORAGE
BLEED TO SOLVENT WASTE TANK
SOLVENT REPURIFICATION
TO VOG
URANIUM LOAD-OUT AND SHIPPING
THORIUM STORAGE
MISC. FLUSHES
HIGH ACTIVITY WASTE ACCUMULATION
CONDENSER
HIGH ACTIVITY WASTE EVAP
SAMPLE TANK
CONDENSER
LALW EVAPORATOR
CONDENSER
NITRIC ACID FRACTIONATOR
CONDENSER
IODINE REMOVAL PARTIAL EVAP.
LOW ACTIVITY LIQUID WASTE FROM BOTH PLANTS
MISC LIQUID WASTE
NEUTRALIZATION TANK
CONDENSER
MLW EVAPORATOR
CONCENTRATED MISC. WASTE
VOG
THOREX PROCESS
TO THOREX VOG
CONCENTRATED HIGH ACTIVITY WASTE STORAGE
EXCESS WATER VAPORIZER
TO LALW EVAPORATOR
SUPER HEATER

MODEL FUEL REPROCESSING PLANT: CASE 1 - BASE CASE

Source: Reference 3-53

DAMES & MOORE

FIGURE 3.25

The General Electric Morris Operation fuel storage facility, which originally was designed as part of a fuel reprocessing plant, has a fuel storage capacity (recently expanded) of 750 tons (3-55). All building air and process vent discharges are passed through a below-grade reinforced concrete tunnel (funnel) with a rectangular cross section of 20 ft^2 at the inlet and decreasing in cross-section toward its sand filter outlet. The condensate from this tunnel is collected in a 3" deep stainless steel floor pan and drained into the off-gas sump. A reinforced 75'x80'x15' concrete structure houses a low velocity sand filter immediately east of the process building and interconnected to the air tunnel described above. The sand filter bed is 8 feet deep and consists of gravel and sand layers. The base of the sand bed is sloped towards the off-gas sump. Air is exhausted from this ventilation exhaust filter by three blowers.

Waste Incinerators

Incineration of combustible low-level radioactive waste is performed at numerous NRC-licensed and DOE facilities throughout the United States. Although the nature of the incinerators varies widely, most incinerators are equipped with little or no off-gas treatment. The control technology employed at the General Electric Nuclear Fuel Plant at Wilmington, North Carolina, which appears to be the most advanced technology utilized, is reviewed below.

The incinerator at the General Electric plant is a Vortex I Vorcinerator with a rated capacity of 1362 kg/hr of waste. The normal feed rate employed is 227 kg/hr. The gas temperature in the incinerator chamber generally ranges from 815-982°C. The vacuum on the furnace generally ranges from a minus 0.5 to a minus 2.0 inches water gauge pressure (-124 to -498 pascals). The gases exiting the incinerator pass through a wet-spray type scrubber used to cool the gases down to 93°C and remove some of the particulates in the effluent. Downstream of the scrubber, the gaseous stream passes through

Waste Management Facilities

This section describes the control technologies for airborne effluents employed at spent (irradiated) fuel storage facilities, waste (trash) incinerators, waste solidification facilities, and agreement state- and NRC-licensed and DOE operated shallow-land burial facilities.

Spent Fuel Storage Facilities

Subsequent to the utilization of nuclear fuel at LWRs, the spent fuel is removed from the core and transferred to an on-site or off-site fuel storage pool. The basic fuel storage facility consists of a cask receiving and handling area (for off-site pools), a semi-gantry type crane for fuel handling, and the pool itself. The pool generally is a reinforced concrete pool filled with water which assists in cooling and shielding of the irradiated fuel material. The gaseous waste systems for Barnwell Fuel Receiving and Storage Station and the General Electric Morris Operation are described below.

The Barnwell fuel pool operates with its Temporary Off-Gas (TOG) system in continuous operation at low flow. The TOG system consists of multiple input lines and headers, a HEPA filter, a silver zeolite molecular sieve bed, and a blower. The TOG has a design flow of 25 cfm under a 11 inch vacuum and the exhaust air is vented through a two-inch pipe vent which rises ten feet above the building roof. The molecular sieve has an iodine retention capability of about 37 grams. The efficiencies of the TOG system are not known precisely. However, particulate removal efficiency of 99.97% for 0.3 micron particles is expected. Average annual estimated releases from the Barnwell fuel storage facility include 58,000 curies of krypton-85, 115 curies of tritium and 18 millicuries of radioiodine (3-56).

TABLE 3-24

Decontamination Factors and Annual Releases for the Model HTGR Reprocessing Plant with Case 1 Airborne Effluent Control Technology*

Nuclides	Decontamination Factors	Curies per year
Tritium	1	1.6E+6
$^{14}\mathrm{C}$	1	7.4E+7
$^{85}\mathrm{Kr}$	1	2.7E+7
$^{220}\mathrm{Rn}$	1.0E+6	8.0E+4
$^{37}\mathrm{Ar}$	1	1.1E+4
$^{129}\mathrm{I}$	20	2.7E+0
$^{131}\mathrm{I}$	60	1.8E+1
$^{222}\mathrm{Rn}$	1	5.8E+1
Semi-volatiles	1.0E+8	8.4E-1
Thorium	5.0E+7	6.2E-3
Uranium	5.0E+7	9.8E-3
All Other Particulates	5.0E+8	7.8E+0

---

* Source : Ref 3-53.

factors and the expected annual effluents from the model HTGR reprocessing plant are given in Table 3-24.

The other cases described in (3-53) are not discussed because most of the technologies are not available for commercial application. These technologies, some of which which are discussed in later sections, include the iodox process, tritium retention, and the krypton absorption in liquid carbon dioxide (KALC) process.

The capital and annual costs for the airborne emission control technology described above are not given in (3-53).

an impingement type mist-eliminator (demister). The gaseous stream is finally passed through a filter housing containing a prefilter and a HEPA bank. Information on costs, efficiency, effluent, and residuals is not available.

Waste Solidification Facilities

Several commercial firms market waste solidification systems for low-level radioactive waste from nuclear facilities. The predominant waste solidification systems employed in U.S. nuclear facilities use portland cement or urea formaldehyde as the solidification agent. Cement and urea formaldehyde systems sold by such vendors as ATCOR, Inc. and Hittman Nuclear & Development Corporation do not create significant off-gas to require control technologies. The solidification agent in either screw extrusion or thin-film evaporator systems such as those marketed by Werner & Pfleiderer Corporation do produce a small off-gas component. The manufacturers recommend the use of HEPA and charcoal filters for off-gas treatment.

Shallow-Land Burial Facilities

Large scale shallow-land burial of low-level radioactive wastes has been carried out at eleven different sites within the United States. Six of these sites are commercially operated under NRC- or agreement state-licenses. The six commercial sites are: the West Valley, New York site operated by Nuclear Fuel Services, Inc.; the Barnwell, South Carolina site operated by Chem-Nuclear Inc.; and the Maxey Flats, Kentucky; Richland, Washington; Sheffield, Illinois; and Beatty, Nevada sites operated by the Nuclear Engineering Company Inc. (NECO). Only the sites at Richland, Beatty, and Barnwell are accepting waste at the present time. The Department of Energy (DOE) operates shallow-land burial facilities for low-level radioactive wastes generated at DOE sites at Oak Ridge National Laboratory, Los Alamos Scientific Laboratory, Hanford Reservation, Idaho National Engineering Laboratory, and the Savannah River Plant.

Burial operations at both commercial and DOE sites generally consists of a cut and cover operation. At the humid sites, the burial trench is only excavated large enough to accommodate the waste available for burial at the time of excavation. At the arid sites, the entire trench is excavated and the trench volume is gradually filled. For both the humid and the arid sites the waste is generally covered with one to three meters of indigenous soil or excavated material.

The primary sources of airborne radioactive emissions at shallow-land burial sites are the gaseous emanations through the soil from the waste trenches, and if surface contamination exists, the fugitive dust emissions from vehicular activity on unpaved roads and areas where little vegetation exists. Surface contamination, which may result from accidental spillages during disposal and/or trench dewatering operations, is generally cleaned up immediately following a contamination event. Control technologies for this type of emission generally consist of road oiling or watering and revegetation.

Very little data exists on radioactive gas emanations from waste burial trenches. Preliminary studies have been performed at West Valley, New York (NFS), Beatty, Nevada (NECO), and Maxey Flats, Kentucky (NECO) which indicate that significant gaseous emissions from burial trenches are not evident. Radionuclides which have been identified in trench gases at these sites include ^{222}Rn, ^{85}Kr, ^{14}C, and tritium. Radon-222 concentrations of up to 83,000 pCi/l have been observed in one of the trenches at West Valley. Similarly, at Beatty, Nevada and Maxey Flats, Kentucky elevated ^{222}Rn has been observed. However, gaseous emanations through the relatively thick trench covers does not appear to be significant based on the available preliminary data. These data suggest emanation rates on the order of 1 to 2 pCi/m^2-sec at a maximum. The available control technology for radioactive gases is generally confinement afforded by the thickness of the trench cover.

REFERENCES

II.3-1 U.S. Nuclear Regulatory Commission. Code of Federal Regulations. Title 10, 1978.

II.3-2 Burchsted, C.A., Kahn, J.E., and Fuller, A.B. Nuclear Air Cleaning Handbook. U.S. Energy Research and Development Administration, ERDA 76-21, 1976.

II.3-3 Kerr-McGee Nuclear Corporation. Final Environmental Statement Related to the Sequoyah Uranium Hexaflouride Plant. NUREG-75/007, Docket No. 40-8027, February, 1975.

II.3-4 Allied Chemical Corporation Nuclear Products. Supplemental Report in Support of Application for Renewal of Source Materials License SUB-526, Uranium Hexaflouride Facility. Docket No. 40-3992, January, 1975.

II.3-5 Allied-Gulf Nuclear Services. Allied Chemical Nuclear Products, Inc. Gulf Oil Corporation. Environmental Report: UF6 Facility. Barnwell Nuclear Fuel Plant, Barnwell, South Carolina, Docket 70-1327-1, June 30, 1972.

II.3-6 U.S. Nuclear Regulatory Commission. Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors. Vol. 3, NUREG-0002, August, 1976.

II.3-7 Sears, M.B. et al. Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle-Conversion of Yellowcake to Uranium Hexaflouride, Part 1. The Flourination-fractionation Process. ORNL/NUREG/TM-7, September, 1977.

REFERENCES (cont'd)

II.3-8 U.S. Atomic Energy Commission. Environmental Survey of the Nuclear Fuel Cycle. WASH-1248, 1972.

II.3-9 U.S. Atomic Energy Commission. AEC Gaseous Diffusion Plant Operations. ORO-684, 1972.

II.3-10 U.S. Energy Research & Development Administration. Final Environmental Statement: Portsmouth Gaseous Diffusion Plant Expansion, Piketon, Ohio. ERDA-1549, 1977.

II.3-11 U.S. Energy, Research & Development Administration. Final Environmental Statement: Expansion of U.S. Uranium Enrichment Capacity. ERDA-1543, 1976.

II.3-12 Mitchell, M.E. Airborne Effluent Control at Fuel Enrichment, Conversion, and Fabrication Plants. KC-1241, 1976.*

II.3-13 Pechin, W.H., et al. Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "as Low as Practicable" Guides - Fabrication of Light-Water Reactor Fuel From Enriched Uranium Dioxide. ORNL-TM-4902, 1975.

II.3-14 Gronier, W.S., et al. Correlation and Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "as Low as Practicable" Guides - Fabrication of Light-Water Reactor Fuels Containing Plutonium. ORNL-TM-4904, 1975.

II.3-15 U.S. Nuclear Regulatory Commission. Source Material License File for Babcock & Wilcox. Docket File #40-1193, Apollo, Pennsylvania, 1978.

* No other information available.

REFERENCES (cont'd)

II.3-16 U.S. Nuclear Regulatory Commission. Special Nuclear Material License File for Babcock & Wilcox. Docket File #70-1201, Lynchburg, Virginia,1978.

II.3-17 U.S. Nuclear Regulatory Commission. Special Nuclear Material License File for Combustion Engineering. Docket File #70-1100, Windsor, Connecticut, 1978.

II.3-18 U.S. Nuclear Regulatory Commission. Special Nuclear Material License File for Combustion Engineering. Docket File #70-36, Hematite, Missouri, 1978.

II.3-19 U.S. Nuclear Regulatory Commission. Special Nuclear Material License File for Exxon Nuclear. Docket File #70-1257, Richland, Washington, 1978.

II.3-20 U.S. Nuclear Regulatory Commission. Special Nuclear Material License File for General Electric Company. Docket File #70-1113, Wilmington, North Carolina, 1978.

II.3-21 U.S. Nuclear Regulatory Commission. Special Nuclear Material License File for Kerr-McGee. Docket File #70-925, Crescent, Oklahoma, 1978.

II.3-22 U.S. Nuclear Regulatory Commission. Special Nuclear Material License File for Nuclear Fuel Services. Docket File #70-143, Erwin, Tennessee, 1978.

II.3-23 U.S. Nuclear Regulatory Commission. Special Nuclear Material License File for Westinghouse Electric Corporation. Docket File #70-1151, Columbia, South Carolina, 1978.

REFERENCES (cont'd)

II.3-24 U.S. Nuclear Regulatory Commission. Special Nuclear Material License File for Batelle-Pacific Northwest Laboratories. Docket File #70-984, Richland, Washington, 1978.

II.3-25 U.S. Nuclear Regulatory Commission. Special Nuclear Material License File for Gulf Oil Corporation. Docket File #70-72, San Diego, California, 1978.

II.3-26 U.S. Nuclear Regulatory Commission. Special Nuclear Material License File for General Electric Company. Docket File #7--754, Vallecitos, California, 1978.

II.3-27 U.S. Nuclear Regulatory Commission. Special Nuclear Material License File for U.S. Nuclear Inc. Docket File #70-1319, Oak Ridge, Tennessee, 1978.

II.3-28 U.S. Nuclear Regulatory Commission. Special Nuclear Material License File for Westinghouse Electric Corporation. Docket File #70-337, Cheswick, Pennsylvania, 1978.

II.3-29 U.S. Atomic Energy Commission. Directorate of Regulatory Standards. Final Environmental Statement Concerning Proposed Rule Making Action: Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion as low as practicable for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents. WASH-1258, Vol. 2, July, 1978.

II.3-30 New York. Power Authority of the State of New York. Final Safety Analysis Report for the James A. Fitzpatrick Nuclear Plant. Docket No. 50-333, Section 11.4, 1978.

REFERENCES (cont'd)

II.3-31 Michels, L.R. and Horton, N.R. "Improved BWR Off-gas Systems," in *Proceedings of the Twelfth AEC Air Cleaning Conference held in Oak Ridge, TN, August 28-31, 1972.* CONF-720823, Vol. 1, January, 1973.

II.3-32 Thomasson, N. "Use of Air Cleaning Systems at Nuclear Power Stations to Meet Lowest Practicable Limits," in *Proceedings of the Twelfth AEC Air Cleaning Conference held in Oak Ridge, TN, August 28-31, 1972.* CONF-720823, Vol. 2, January, 1973.

II.3-33 General Electric Co. Personal communication, Lloyd Nesbitt, 1979.

II.3-34 New York. Power Authority of the State of New York. Personal communication, Alan McKeen, 1979.

II.3-35 Nebraska. Public Power District. Personal communication,* 1979.

II.3-36 Philadelphia Electric Co. Personal communication, Mike Sullivan, 1979.

II.3-37 U.S. Environmental Protection Agency. *Radiological Quality of the Environment in the United States, 1977.* EPA 520/1-7-009, September, 1977.

II.3-38 Commonwealth Edison Co. *Preliminary Safety Analysis Report for the Zion Atomic Power Station, Units 1 and 2.* Dockets 50-295 and 50-304, Section 11, 1978.

* Individual chose to remain anonymous.

REFERENCES (cont'd)

II.3-39 Consolidated Edison Company. Final Facility Description and Safety Analysis Report for the Indian Point Nuclear Generating Unit No. 2., Docket No. 50-247.

II.3-40 Commonwealth Edison Co. Personal communication, Lewis Liberatori, 1979.

II.3-41 Commonwealth Edison Co. Personal communication, Bob Johnson, 1979.

II.3-42 New Hampshire. Public Service Company. Preliminary Safety Analysis Report for the Seabrook Station. Dockets 50-443 and 50-444, Sections 11.6.4 and 12.2, June, 1973.

II.3-43 California. Sacramento Municipal Utility District. Personal communication, Roger Miller, 1979.

II.3-44 U.S. Nuclear Regulatory Commission. Facilities License Application Record, May 31, 1978.

II.3-45 Lamarsh, J.R. Introduction to Nuclear Engineering. Reading, MA: Addison-Wesley Publishing Company, 1975.

II.3-46 Colorado. Public Service Company. Personal communication, Don Alexander, 1979.

II.3-47 Colorado. Public Service Company. Preliminary Safety Analysis Report for the Fort Saint Vrain Nuclear Generating Station. Docket 50-267, Section 11.1.1 and 11.1.2, September, 1966.

II.3-48 U.S. Department of Energy. Division of Nuclear Power Development. Assistant Secretary of Energy Technology.

REFERENCES (cont'd)

U.S. Central Station Nuclear Electric Generating Units: Significant milestones (Status as of July 1, 1978). DOE/ET-0030/2 (78), UC-2, 1978.

II.3-49 Project Management Corporation. Preliminary Safety Analysis Report for the Clinch River Breeder Project. Docket No. 50-537, Vol., 7, Section 11.3, 1978.

II.3-50 Power Reactor Development Company. Technical Information and Hazards Summary Report for the Enrico Fermi Atomic Power Plant. Docket No. 50-016, 1978.

II.3-51 Finney, B.C., et al. Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "As Low As Practicable" Guides - Nuclear Fuel Reprocessing. ORNL-TM-4901, 1975.

II.3-52 Allied-Gulf Nuclear Services. Barnwell Nuclear Fuel Plant Environmental Report. Docket No. 50-332, November, 1971.

II.3-53 Davis, W. et al. Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle - Reprocessing of High Temperature Gas-Cooled Reactor Fuel Containing U-233 and Thorium. ORNL/NUREG/TM-4, 1976.

II.3-54 Perkins, B.L. Incineration Facilities for Treatment of Radioactive Wastes: A Review. Los Alamos, New Mexico: Los Alamos Scientific Laboratory of the University of California, LA-6252, 1976.

REFERENCES (cont'd)

II.3-55 U.S. Nuclear Regulatory Commission. Consolidated Safety Analysis Report from General Electric, Morris Operation. Docket File #70-1308, Special Nuclear Material License File, 1978.

II.3-56 U.S. Nuclear Regulatory Commission. Environmental Statement Barnwell Fuel Receiving and Storage Station. NUREG-0008, 1976.

II.3-57 Finney, B.C., et al. Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle - Reprocessing of Light-Water Reactor Fuel. ORNL/NUREG/TM-6, 1977.

CHAPTER II

Section 4: Other NRC-Licensed and DOE Facilities

This section considers current control technologies utilized for reduction of airborne radionuclide emissions from facilities not directly associated with the nuclear fuel cycle (see Figure 3.1). These facilities are licensed by the NRC in accordance with the applicable sections of Code of Federal Regulations Title 10 (4-1) and/or are owned and operated by the DOE.

The facilities considered below are: reactors other than central station nuclear power plants; "special nuclear material" and "source material" licensees not considered in the previous section; "by-product material" licensees; high energy accelerators; fusion energy facilities; weapons systems associated facilities; and several national laboratories for which environmental reports and/or similar types of information exists.

Reactors

The U.S. Nuclear Regulatory Commission issues operating licenses to various types of reactors other than central station nuclear power plants (4-1). The NRC Facilities License Application Record (4-2) designates facilities as "operating" or "not operating" and shows: one license in effect for operating and five licenses in effect for not operating "experimental and test reactors"; one license in effect for a not operating "propulsion reactor"; sixty-six licenses in effect for operating and eight licenses in effect for not operating "research reactors"; and four licenses in effect for operating "critical experiment facilities". This subsection examines the current airborne emission control technologies for an "experimental and test reactor", a "critical experiment facility", and six "research reactors".

The information on the airborne emission control technologies for these facilities are summarized in Table 4-1.

The research reactors examined, composed of five university reactors and the Union Carbide reactor at Tuxedo, N.Y., are light water pool reactors utilizing natural convection core cooling. These reactors consist of fixed cores resting at the bottom of metal tanks. Light water surrounding the core provides shielding and cooling by natural convection. All of the presently operating reactors operate predominantly at a steady state power rather than through pulsing.

In these reactors, neutron irradiation of dissolved air in pool water produces nitrogen-16 (half life = 7 seconds) and argon-41 (half life = 1.83 hours). Argon-41 is the sole radionuclide detected in gaseous releases from the university reactors with the exception of tritium which was also detected in one of the reactors. The argon releases are usually just above the detection level. Releases from the Union Carbide reactor in Tuxedo, New York (whose purpose is radiochemical production for the pharmaceutical industry) include fission product gases such as xenon and krypton, in addition to argon-41 (4-3). Radioiodine that is produced remains dissolved in the pool water (4-3). The control employed for routine releases from the light water pool reactors range from none at all (Union Carbide, University of California at Irvine, and Michigan State University; 4-3, 4-4, 4-5) to the use of roughing plus HEPA filter banks (Columbia University, Massachusetts Institute of Technology and North Carolina State University; 4-6, 4-7, 4-8).

The only existing operational "experimental and test reactor" is the National Bureau of Standards reactor, which is a non-pool type reactor utilizing a heavy water moderator and enriched fuel (4-9). It is operated in the steady state power mode and is the focus of a large number of experiments by various government agencies. There are two exhaust lines for routine reactor operation; one for the beam

TABLE 4-1

Control Technologies Utilized for Reduction of Routine Airborne Radionuclide Emissions at Research and Test Reactors

Facility	Type of Reactor	Control Technology	Efficiency	Operational Conditions and/or Comments
Columbia University New York, NY; Authorized for 250 KW at at steady state operation license issued 4/14/77	TRIGA-Mark II pool reactor; natural convection cooling (Not operating)	Reactor Exhaust: Pre-filter followed by HEPA filters Pneumatic Tube: HEPA filter	Overall reactor exhaust system: 99.95% by DOP testing	To be operated primarily at steady state.
Massachusetts Institute of Technology, Cambridge, Mass; Authorized for 5000 KW at steady state operation; license issued 6/9/58.	Rebuilt commercially available pool type reactor; natural convection cooling (Operational)	Six parallel filter banks each consisting of a pre-filter and HEPA filter in series	---	Primarily operated at steady state; annual maintenance costs for the control system are on the order of $1000.
North Carolina State University, Raleigh, NC Authorized for 1000 KW at steady state operation; license issued 8/25/72.	Pulstar pool reactor (Operational)	General Reactor Bay: Two roughing filters Thermal Column: HEPA filter plus General Reactor Bay filters	Two roughing filters in series: 8% and 80% NBS rated.	Primarily operated at steady state; annual maintenance cost for each of the systems are on the order of $1000.
Michigan State University East Lansing, Michigan Authorized for 250 KW at at steady state operation; license issued 3/21/69.	TRIGA-Mark I pool reactor; natural convection cooling (Operational)	None for routine releases	---	---

TABLE 4-1 (continued)

Control Technologies Utilized for Reduction of Routine Airborne Radionuclide Emissions at Research and Test Reactors

Facility	Type of Reactor	Control Technology	Efficiency	Operational Conditions and/or Comments
University of California at Irvine, Irvine, Ca. Authorized for 250 KW at steady state operation; license issued 11/24/69.	TRIGA-Mark I pool reactor, natural convection cooling (Operational)	None for routine releases	---	Primarily operated at steady state.
Union Carbide, Tuxedo, NY; Authorized for 5000 KW at steady state operation; license issued 9/7/61.	AMF pool reactor (Operational)	None for routine releases	---	Operated at steady state. Argon-41 and noble gases detected in airborne releases.
National Bureau of Standards Gaithersburg, Maryland Authorized for 10MW(e) at steady state operation provisional licence issued 11/23/67; full-time license issued 6/30/70	Heavy water moderated, 93% enriched fuel (Operational)	Beam Tube Air: Pre-filter plus 11 second holdup Reactor Building Air: Pre-filter plus HEPA filter plus eleven second holdup	---	Operated at steady state. Pre-filters changed at a frequency of less than once per year.
Plutonium Recycle Critical Facility, Battelle Memorial Institute, Richland, Wa. license issued 11/29/71.	Low power research reactor, has been operated with both heavy and light water moderators (Operational)	Particulate (HEPA) filter bank plus activated charcoal filter bank	99.95% for particles greater than 0.3 um. 95% for iodine removal	Operated at both steady state and pulsing modes.

tube air (the air from the area immediately surrounding the reactor), and the other for the reactor building air. Air in both exhaust lines is passed through a prefilter followed by a HEPA filter. The HEPAs are followed in each line by an eleven second holdup prior to release to the stack. In place dioctyl phthalate (DOP) tests have shown the particulate removal efficiency of the filtration systems to be greater than 99.99%.(4-12) The HEPA filters have never been changed and pre-filters are changed irregularly, less than once per year (4-9 and 4-10). Argon-41 and some tritium are released in gaseous effluents from the reactor (4-10).

The other reactor examined was the plutonium recycle critical experiment facility located at Richland, Washington and operated by Battelle Memorial Institute. This reactor, which is designated as a "critical experiment facility" by the NRC, is a low-power research reactor designed for determining the reactor/nuclear parameters of heterogeneous reactor systems (4-11). It is operated in both the steady state and pulsing modes and is designed so that the reactor lattice and controls can be easily changed. Gaseous effluents are routed through a bank of HEPA filters and activated charcoal filters in series prior to release through a 150 foot high stack. The activated charcoal filters at this reactor have a 95% removal efficiency for iodine (4-11).

The exemplary control technology for these reactors appears to be the particulate filter systems (pre-filter and/or HEPA filter), if they are applicable to the particular reactor system and mode of operation.

Other Special Nuclear Material and Source Material Licensees

This subsection considers those facilities that hold a "special nuclear material" license and/or a "source material" license and which were not considered in the previous section on the nuclear fuel cycle facilities.

Special nuclear material means "(1) plutonium, uranium 233, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the (Nuclear Regulatory) Commission, pursuant to the provisions of section 51 of the (1954 Atomic Energy) act, determines to be special nuclear material, but does not include source material; or (2) any material artificially enriched by any of the foregoing but does not include source materaial;"(4-1). Six special nuclear material license amendments or applications were examined to determine the control technologies employed for reduction of airborne radionuclide emissions (4-12 through 4-18). The information on these facilities and their control technologies are summarized in Table 4-2.

The types and amounts of special nuclear materials in question and the control technologies to be employed are presented in Table 4-2. The usages of special nuclear materials discussed in the submittals include research and development; instrumentation calibration, isotope dilution; and the analyses of nuclear fuel materials, biological specimens, environmental samples, and geological samples (4-12 through 4-18). Pre-filters and HEPA filters in series are the only controls for airborne radionuclide release mentioned by four of the applicant/licensees. These filter combinations are utilized on exhaust of glove boxes, room exhausts, and building exhausts. In most cases involving work with special nuclear material, ventilation air is subjected to filtering to remove airborne radioactivity prior to atmospheric exhaust. The two glove boxes in the hot laboratory of Isotopes Westwood Laboratories which exhaust the ventilation air from

TABLE 4-2

Control Technologies Employed by Special Nuclear Material Licensees in Reducing Routine Airborne Radionuclide Releases

Facility/Document	Special Nuclear Material Usages	Type of Material and Quantity	Control Technology
Atomic International (A Division of North American Aviation, Inc.) Canoga Park, CA. Safety Report 3/1/67.	Nuclear research & development work concerning reactors	Various types of special nuclear material involved with fuel fabrication or reactor operation	Depending on the radioactive material being handled, pre-filters and HEPA filters on the facility exhaust system, and inlet and exhaust of glove boxes and fume hoods.
Isotopes (A wholly-owned subsidiary of Teledyne, Inc.) Westwood Laboratories, Westwood, NJ Application for renewal of a special nuclear material license, 11/18/68	Analysis of nuclear fuel materials, biological samples, environmental samples, and geological samples; research and development; studies of nuclear parameters; isotope dilution and calibration of radioassay equipment.	Request authorization to possess and use: Pu-236 2 ug Pu-239 1 ug Other Pu 0.5 ug U-233 1 g U-235 510 g U-232 1 ug	Once-through air system with a HEPA on the inlet side and two HEPA filter-charcoal filter combinations in series on the exhaust side.
Union Carbide Corp. Tuxedo, NY. License amendment application, 1976.	---	Various types	All exhaust air from the hot laboratory passes through roughing and HEPA filters prior to discharge

TABLE 4-2 (continued)

Control Technologies Employed by Special Nuclear Material Licensees in Reducing Routine Airborne Radionuclide Releases

Facility/Document	Special Nuclear Material Usages	Type of Material and Quantity	Control Technology
National Aeronautics & Space Administration, Langley Research Center, Hampton, Va. Application dated 6/14/76 for extention of special nuclear material license.	Gas laser research	Up to 190 g of uranium-235 in gaseous UF_6 form (90% or greater enriched)	Exhaust gases pass through a HEPA filter prior to venting to the atmosphere
Reactive Metals, Inc., Extrusion Plant, Ashtabula, Ohio. Application for a special nuclear materials license, 10/66	Fabrication of metallic enriched uranium	Enriched uranium metal	None mentioned
Todd Shipyards Corp., Research & Technical Division, Galveston, TX/ License amendment application 2/13/76	Modification of fuel elements in a new work area	Enriched uranium contained in unirradiated N.S. Savannah Core II fuel elements. 36 fuel elements	Exhaust from the Facilities Building pass through a HEPA filter before discharge to the atmosphere.

the lab are each equipped with two HEPA plus charcoal filter banks in series for treatment of exhaust (4-13).

Source material is defined as "(1) uranium or thorium, or any combination thereof, in any physical or chemical form or (2) ores which contain by weight one-twentieth of one percent (0.05%) or more of (i) uranium, (ii) thorium or (iii) any combination thereof. Source material does not include special nuclear material."(4-1, Part 40). Seven source material licenses and/or license applications were examined for the control technologies employed for reduction of airborne radionuclide emissions (4-19 through 4-25). The information on these facilities and their control technologies is summarized in Table 4-3.

The facilities examined used source material in research and development, for manufacturing thorium-magnesium alloy, for assorted purposes at a U.S. Air Force Base, or required the license for handling unwanted or waste source material (4-19 through 4-25). The types and amounts of source materials in question and the control technologies are presented in Table 4-3. The control technologies employed range from HEPA filters to wet scrubbers. Exhaust systems containing HEPA filters are used at Bell Laboratories and the Westinghouse Electric Corporation. A 2500 scfm wet scrubber is used to collect dust from the grinding operation at the Chicago Magnesium Casting Company (4-21), whereas an unspecified type of dust collector is used in the exhaust line from the refractory lined steel shell at the metallurgical plant of Molycorp, Inc.(4-23).

TABLE 4-3

Control Technologies Employed by Source Material Licensees in Reducing Routine Airborne Radionuclide Releases

Facility/Document	Source Material Usage	Type of Material	Maximum Amount At Any One Time	Control Technology
African Metals Corp. New York, NY License application dated 7/15/74.	Tailings from the processing of Belgian Congo pitchblende is planned for storage in Fernald, Ohio in 2 silos	Silo #1: 0.13% Uranium		None
		Silo #2: 0.19% Uranium		
		Total Source Material	27,536 lbs.	
Bell Telephone Labs. Inc., Murray Hill NJ. License application received 11/4/77.	Research & development in the telecommunication industry	Natural U: oxides, metals	20 lbs.	Exhaust from radiation lab is passed through HEPA filters.
		Depleted U: oxides, metals	20 lbs	
		Thorium : oxides, fluorides	70 lbs.	
		Total Source Material	100 lbs	
Chicago Magnesium Casting, Co. Blue Island, Ill. Amendment to license dated 7/18/72.	Manufacture of 4% thorium-magnesium alloy sand castings	40%. Th- bal. magnesium	20 lbs.	2500 cfm wet dust scrubber for the grinding operation
		Total Source Material	1,000 lbs.	
Minnesota Mining & Manufacturing Co. St. Paul, Minn. License application dated 4/4/74.	As a catalyst in one of the resin systems at the 3M Industrial Electric Products Division, Rutland, VT	Natural U: In any form, primarily uranyl nitrate	75 lbs	Not specified
		Depleted U: Hexahydrate		
		Total Source Material	75 lbs	

TABLE 4-3 (continued)

Control Technologies Employed by Source Material Licensees in Reducing Routine Airborne Radionuclide Releases

Facility/Document	Source Material Usage	Type of Material	Maximum Amount At Any One Time	Control Technology
Molycorp, Inc, White Plains, NY Renewal application dated 12/26/74.	Columbium ore concentrate contains small quantities of unwanted natural thorium ore ferro-columbium alloy	Th: Any chemical form, in ore concentrates, containing 1-1.59%. Total Source Material	80,000 lbs. 80,000 lbs.	Dust collector in the exhaust line from the refractory lined steel shell.
Westinghouse Electric Corp. Research and Development Center, Pittsburg, PA. Amendment application to license dated 11/1/73.	Research and development that will involve various chemical, metallurgical and/or physical processes	Natural U: Any form Depleted U: Any form Thorium : Any form Total Source Material	1,200 kg 1,200 kg 10 kg 1,200 kg	Exhaust systems contain a filter and fan, which are used when potential for producing airborne radionuclides exists.
Wright-Patterson Air Force Base, Ohio. Renewal application dated 7/18/72.	Shielding, counterweight, instrument calibration, spikes, tracers, research, storage, alloys.	Natural U: Metal Depleted U: Metal Thorium: Any form Total Source Material	20.56 lbs. 2488.22 lbs. 25.5 lbs. 2534.3 lbs	Not specified

By-Product Material Licensees

This subsection considers airborne emission control technologies utilized in facilities that hold a "by-product material" license. By-product material is defined as "any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material"(4-1). By-product materials include all fission products and neutron activation products (exclusive of special nuclear material). Commonly known by-product materials include ^{137}Cs, ^{134}Cs, ^{133}Xe, ^{131}I, ^{99}Mo, ^{99m}Tc, ^{90}Sr, ^{85}Kr, ^{63}Ni, ^{60}Co, ^{14}C, and tritium.

The licensing of byproduct materials in the United States is performed by the U.S. NRC or by a cognizant authority in an agreement state. An agreement state is any state with which the Nuclear Regulatory Commission has an effective agreement under subsection 2746 of the Atomic Energy Act of 1954.(4-1). There are twenty-five agreement states and twenty-five non-agreement states in the United States. The U.S. NRC has, as of January 31, 1979, 7457 byproduct material licenses in effect. The number of byproduct material licenses in effect issued by agreement states is probably of the same magnitude. The 7457 by-product material licences issued by the U.S. NRC includes 4314 industrial, 2672 medical, 374 academic, and 97 civil defense licenses. The majority of civil defense licenses are for low-radioactivity sealed sources for calibrating Geiger-Mueller detectors. Accordingly, civil defense licenses were excluded from this study and a small random sampling of licenses of the industrial, academic, and medical type was made.

The byproduct material files are quite voluminous, contain large quantities of information irrelevant to this study, and do not contain safety analyses as is the case for reactor licensing files. The principal source of information for this study comes from the response to item 13 on the byproduct material license application which asks for information on the facilities and equipment employed by the prospective licensee for handling the material. These facilities and equipment include fume hoods, shielding, glove boxes, remote handling equipment and in some cases the air cleaning systems. Since byproduct material licenses are not kept in the public document room of the NRC, a special appointment to peruse the by-product material license files was necessary. A request to examine 65 license files was made. From this total, information of varying relevance and import was obtained from 63 license files (two licenses were pending). Of these 63 files, 17 were licenses to academic institutions, 16 were medical licenses, and 30 were industrial licenses. The control technology and effluent data obtained from these licenses are described below.

Academic By-Product Material Licenses

The majority of the academic licenses examined were of the broad specific type; broad in the sense that any byproduct material with atomic numbers 1 through 83 in any physical form could be possessed and specific with regard to quantity limits for each radionuclide and the maximum total activity. The byproduct materials at academic institutions are used for research and development, as calibration sources, detector sources, as target material for accelarators, in biological in-vitro studies, and as neutron sources. A sizeable fraction of the materials are in sealed or containerized form and thus, there are no airborne effluents. The airborne emission control technologies employed by academic byproduct licensees are generally HEPA filtered fume hoods, hot cells, and glove boxes, and activated charcoal traps for radioxenon and radioiodine removal. A review of academic licensee data is presented in Table 4-4.

Industrial By-Product Material Licensees

The majority of industrial byproduct licensees use sealed gamma or beta sources and thus, do not require control technology. Some industrial applications include well-logging thickness gauges, gas

TABLE 4-4

Academic By-Product Material Licenses

Licensee/License Number	By-Product Materials (BPM)	BPM Use	Control Technology
University of Toledo, Toledo, Ohio (34-10247-06)	Any BPM with z=3-83; plated and sealed americium-241 sources; tritiated titanium foil	Research	None Described
University of Rhode Island Kingston, Rhode Island (38-03260-14)	Any BPM with z=3-83; tritiated titanium foils sealed neutron sources (Am/Be)	Research	None Described
Merrimack College North Andover, Massachusetts (20-08852-02)	As specified in Section 33.100 schedule A of 10 CFR 33	Biological Research	None Described
St. Louis University St. Louis, Missouri (24-00196-07)	Any BPM with z=3-83; sealed cesium-127 and cobalt-60 sources	Research	None Described
Virginia Polytechnic Institute and State University Blacksburg, Virginia (45-09475-30)	Any BPM with z=3-83; target material tritium sealed americium sources	Educational and resource use; tritium in pulsed accelerator; americium sources for calibration and instrumental analysis	None Described
Pennsylvania State University University Park, Pennsylvania (37-00185-04)	Any BPM with z=3-83 Any BPM with z=89-98 Sealed Am/Be source Sealed Am/Be and cesium-137 sources	Research Fallout Research Research & Teaching Moisture - Density Gauges	Various control technologies at 117 different labs ranging from no control for zero air-borne effluent labs to hot cells and gloveboxes. Fume hoods with HEPA filtration employed when necessary.

TABLE 4-4 (continued)

Licensee/License Number	By-Product Materials (BPM)	BPM Use	Control Technology
Miami University Oxford, Ohio (34-01329-07)	Any BPM with z=3-83 Sealed americium and Cf-252 neutron source	Research	None Described
Boston University Boston, Massachusetts (20-00805-11)	Any BPM with z=3-83 Sealed strontium-90 and cobalt-60 sources Tritium and nickel-63 foil	Research; Gas chromotograph; Detector Cell	All volatiles handled in fume hoods equipped with charcoal and/or HEPA filters; gloveboxes with HEPA filtration used where necessary.
Northwestern University Evanston, Illinois (12-00382-03)	Any BPM with z=3-83 Sealed americium source Sealed strontium-90 sources Up to 2 Ci of xenon-133 (free gas or solution)	Research	None Described
Reactors and Visitors University of Virginia Charlottesville, Virginia (45-00034-26)	Any BPM with z=3-98 with half-life <14.3 days, xenon-133	Research	Xenon shipped in gaseous form, is then dissolved and stored as liquid; all xenon transfers are performed in a closed system. Radioactive inert gases are discharged through filtered fume hoods.
Wayne State University Detroit, Michigan (21-00741-08)	Any BPM with z=3-83 Tritium as sealed source	Research Target for neutron generator	None Described
Howard University Washington, DC (08-00386-19)	Any BPM with z=3-83 Sealed amercium and californium sources		Activated charcoal traps (90% efficiency) are used in xenon-133 studies.

TABLE 4-4 (continued)

Licensee/License Number	By-Product Materials (BPM)	BPM Use	Control Technology
University of Lowell Lowell, Massachusetts (20-07446-01)	Any BPM with z=3-83 sealed cesium-137 and californium-241 sources	Research	Fume hood use for volatiles and dispersible contaminants
Ferris State College Big Rapids, Michigan (21-15237-01)	Any BPM with z=3-83 Sealed cesium-137 and nickel-63 sources	Research	Fume hood use for volatiles and dispersible contaminants
Ohio State University Columbus, Ohio (34-00293-02)	Any BPM with z=3-83 Polonium/beryllium source Tritium gas Sealed tritium sources	Research Target materials or detector cells	All projects involving volatile or dispersible contaminants use fume hoods with face velocities greater than 100 fpm.
University of Pennsylvania Philadelphia, Pa. (37-00118-07)	Any BPM with z=3-83 Sealed americium-241 californium-252 sources, neptunium-237 and thorium-228	Research	HEPA filters used for particulates and charcoal canisters for volatiles
University of Michigan Ann Arbor, Michigan (21-00215-04)	Any BPM with z=3-83 Sealed polonium-210, californium-252, americium-241 sources	Research	Over 300 laboratories using BPM; HEPA filtration, charcoal filters, glove boxes, hot cells employed as needed

Notes:
a) z = atomic number
b) specific amendments to licenses are not necessarily included
c) total amounts allowed for each licensee vary widely
d) source of information for table is from each individual license file

chromatographic detector cells, fabrication of calibration sources and smoke detectors, petrochemical research, self-luminous dial and gauge manufacture, and for process tracers studies. The airborne emission control technologies for industrial licensees handling dispersible radiocontaminants include HEPA filtered fume hoods, glove boxes, and hot cells as well as activated charcoal traps for radioxenon and radioiodine removal. A review of industrial licensee data is presented in Table 4-5.

Medical By-Product Material Licensees

Only "broad" medical byproduct material licenses were examined. These licenses cover both research applications and human uses of byproduct material, and the control technologies employed include HEPA filtered fume hoods, glove boxes, and hot cells for laboratory work and activated charcoal traps for radioxenon and radioiodine removal. Some hospital incinerators employ wet scrubbers and filtration. A review of medical licensee data is presented in Table 4-6.

The groups of medical uses (mentioned in Table 4-6) of byproducts include the following from Schedule A of 10 CFR 35.100 (Ref 4-1). Groups I or II radionuclides are for use in the preparation of radiopharmaceuticals for specific diagnostic studies involving measurements of uptake, dilution, and excretion, or for imaging and tumor localization, respectively. Group III radionuclides are used for generators and reagent kits for the preparation and use of radiopharmaceuticals for certain diagnostics uses; Group IV radionuclides are used for certain therapeutic uses that do not normally require hospitalization for purposes of radiation safety; Group V radionuclides are used for the preparation of therapeutic radiopharmaceuticals such as gold-198, as a colloid for use as intracavitary treatment of malignant effusions, iodine-131 as iodide for treatment of thyroid carcinoma or any byproduct material used for therapeutics; and Group VI radionuclides are used for various medical applications including bone mineral analysis, and intercavitary treatment of cancer.

TABLE 4-5

Industrial By-Product Material Licenses

Licensee/License Number	By-Product Materials (BPM)	BPM Use	Control Technology
Uniroyal, Inc. Stoughton, Wisconsin (48-02238-01)	Sealed Strontium-90 source	Measurement of film and film fabric laminate thickness	None Required
Capintec Instrument, Inc. Pittsburgh, Pa. (37-14179-03)	Any BPM with z=1-83 except for alpha emitters; americium-241 molybdenum-99	Isotope sources Measuring instruments	None Described
Madison Metropolitan Sewage District, Madison, Wisconsin (48-16604-01)	Sealed nickel-63 source	Gas chromatography (Detector cell)	None Required
MG Technical Products Kearny, New Jersey (29-15830-01)	Nickel-63 foil	Gas chromatography (Detector cell)	None Required
National By-Products Mason City, Illinois (12-15904-01)	Nickel-63 foil	Gas chromatography (Detector cell)	None Required
Uniroyal, Inc. Naugatuck, Connecticut (06-00221-07)	Sealed strontium-90 source	Beta gauge for uncured rubber stack measurements	None Required
Republic Industries, Inc. Division of Dor-O-Matic (12-15641-01)	Americium-241 foil sources	Assembly of fire detection units for commercial distribution	None Required
Kay-Ray, Incorporated Palatine, Illinois (12-11184-01)	Sealed cobalt-60, cesium-137, and americium-241 sources	Development, production, distribution and servicing of gauging equipment	None Required

TABLE 4-5 (continued)

Licensee/License Number	By-Product Materials (BPM)	BPM Use	Control Technology
Standard Oil Company of Indiana, Naperville, Ill. (12-13837-01)	Any BPM with z=3-83 Sealed Co-60, Cs-137, Am-241, and Sr-90 sources; Argon-41.	Petroleum and petrochemical research argon-41 used in pilot plant flow study	None Described
Exxon Research & Engineering Co. and Exxon Chemicals, Chemical Technology Dept. Linden, NJ. (29-5260)	Any BPM z=3-83	Petroleum and petrochemical research	Fume hoods and roughing filters, glove box with HEPA employed where needed
Soiltest, Inc. Evanston, Illinois (12-13793-01)	Sealed americium-241/cesium-137 sources	Demonstration and distribution of nuclear soil moisture gauges	None Required
AAR Corporation Elk Grove Village, Illinois (12-13665-01)	Tritium	Self-luminous dials and meter movement indicators	Hood blower and HEPA filtration before exhaust
Atlantic Richfield Company Harvey, Illinois (12-00140-04)	Tritium Any BPM with z=3-83 Sealed americium-241 source	Research, tracer tests in gasoline production units and hydrogenetion units; fuel oil in vacuum towers and cokers	Radiochemical fume hoods
American Nuclear Products Springfield, Missouri (24-16379-02)	Any BPM with z=3-83	Manufacture of calibration sources	Fume hood with HEPA filtration
Canberra Industries Meridan, Connecticut (06-15099-01)	Sealed Am-241, Cd-109, Fe-55, Cs-137, Co-60, Po-210, Th-228, Gd-153, Bi-210, C-14, Cl-36, Pm-147, Sr-90, Tc-99, Ba-133, and Mn-54 sources	Instrument checking and calibration	None Required

TABLE 4-5 (continued)

Licensee/License Number	By-Product Materials (BPM)	BPM Use	Control Technology
Combustion Engineering, Inc. Power Systems Group, Windsor, Connecticut (06-00217-06)	Any BPM with z=1-83, including irradiated or contaminated reactor components and coolant water; sealed neutron sources	Research; maintenance repair, decontamination and study of reactor components	Pressure zonation; exhaust and glove box HEPA filtration
United Technologies Corp. Sikorsky Aircraft Division Stratford, Connecticut (06-02269-03)	Tritium Strontium-90	Self luminous parts for aircraft instruments	None Required
Wheeling-Pittsburgh Steel Corp. Pittsburg, Pa. (37-16179-01)	Sealed cesium-137 sources	Use in coke guide and pusher machine for materials inventory	None Required
Consolidated Coal Company Evansville, Indiana (13-16712-01)	Sealed cesium-137 source Sealed americium-241 source	Well logging for exploration purposes	None Required
Industrial Nuclear Company, Inc., Overland, Missouri (24-12585-01)	Iodine-125, iodine-131, and cesium-137	Radiochemical manufacture and instrument calibration	Pressure zonation; HEPA filtered glovebox and hood
Packard Instrument Company, Inc., Downers Grove, Ill. (12-04933-02)	Any BPM with z=3-83 Tritiated foils Ni-63 foil, Pm-147	Research, calibration manufacture	1500-2000 cfm hood with filtration
Panametrics, Incorporated Waltham, Massachusetts (20-07181-01)	Kr-85, Ar-37, Xe-133, Pm-147, Po-210, Tc-99. Sealed Am-241, Fe-55, Pm-147 and deposited Cm-242 and Cm-244 sources.	Research manufacture	None Described
Varian Associates, Inc. Geneva, Illinois (12-11166-01)	Krypton-85	Manufacturing and testing of electron tubes	None Described

TABLE 4-5 (continued)

Licensee/License Number	By-Product Materials (BPM)	BPM Use	Control Technology
Matheson Gas Products East Rutherford, New Jersey (29-03829-01)	Compressed gas mixtures including C-14, tritium, Kr-85, S-35, Ni-63, and tritiated compounds	Storage and distribution, gas chromatographs	All materials handled in sealed containers; no control required.
U.S. Department of the Army Fort Monmouth, New Jersey (29-01022-06)	Any BPM with z=1-83	Research	Hood and glove boxes equipped with HEPA filtrations
U.S. Department of the Army Army Troop Support Command St. Louis, Mo. (24-12705-01)	Tritiated Paint Tritiated Gas	Produce illumination in lensatic compasses	None Described
U.S. Department of the Army Armament Research and Development Command, Dover, NJ. (29-00047-02)	Any BPM with z=3-83 Tritiated foils, sealed Am-241, Cf-252, Kr-85, Pm-147, Th-204, and Sr-90 sources.	Research	None Described
U.S. Department of the Navy Naval Research Laboratory Washington, DC (08-01393-02)	Any BPM; sealed Cs-137, Co-60, Pu, U-235 sources, encapsulated plutonium foils	Research and calibration	Filtered ventilation
U.S. Department of Commerce National Bureau of Standards Washington, DC (08-00566-95)	Any BPM	Research; standard manufacture calibration	None Described
U.S. Department of the Air Force Cambridge Research Laboratories Bedford, Mass. (20-03095-02)	Any BPM with z=1-84	Research	HEPA filtered ventilation

Notes:
a) z = atomic number
b) specific amendments to licenses are not necessarily included
c) total amounts allowed for each licensee vary widely
d) source of information for table is from each individual license file

TABLE 4-6

Medical By-Product Material Licenses

Licensee/License Number	By-Product Materials (BPM)	BPM Use	Control Technology
The Medical College of Pennsylvania, Philadelphia, Pa. (37-07438-15)	Any BPM with z=3-83	Research	None Described
Kent General Hospital Denver, Delaware (07-14850-01)	Any BPM listed in Groups I, and III, IV of schedule A, 10 CFR 30.100	Human Diagnostics and Therapy	None Described
Veterans Administration, Lakeside Hospital, Chicago, Ill. (12-02642-06)	Any BPM with z=3-83 Molybdenum-99 Sealed strontium source	Research, Human Diagnostics and Therapy, technitium-99 generator,	None Described
Diagnostic Photon Corporation Canovanas, Puerto Rico (52-16345-01)	Molybdenum-99 Technitium-99	Technetium-99 generator, Preoperation of pertechnatate solution	None Described
Northeastern Ohio General Hospital North Madison, Ohio (34-16763-01)	Any BPM listed in Groups I, II, and III of Schedule A, 10 CFR 35.100. Any BPM listed in 10 CFR 31.11	Human Diagnostics In vitro studies	None Described
Knox County General Hospital Rockland, Maine (18-15864-01)	Any BPM listed in Groups II, and III of schedule A, 10 CFR 35.100; I-131, Cs-137	Human Diagnostics Treatment of hyperthyroidism or cardiac disfunction calibration	None Described
National Health Laboratories, Inc. Vienna, Virginia. (45-15355-01)	Tritium, C-14, P-32, S-35, Ca-45, Cr-51, Fe-55, Fe-59, and I-129.	In vitro clinical radioassays	None Described
Cook County Hospital Dept.of Radiation Therapy and Nuclear Medicine, Chicago, Ill (12-00010-05)	Any BPM listed in all groups of shedule A of 10 CFR 35.100. Any BPM with z=3-83; sealed americium source.	Human Diagnostics and Therapy; radiopharmaceutical preoperation; research; X-ray	3000-4700 cfm exhaust fans used in xenon hot lab and scan room

TABLE 4-6 (continued)

Licensee/License Number	By-Product Materials (BPM)	BPM Use	Control Technology
Beth Israel Hospital Boston, Massachusetts (20-00742-18)	Any BPM with z=3-83	Research Human Diagnostics and Therapy	Douglas bags and fume hoods employed for xenon-133 discharge
The Medical College of Wisconsin, Milwaukee, Wisconsin (48-00547-19)	Any BPM with z=3-83	Research	Fume hood
County General Hospital Milwaukee, Wisconsin (48-04193-1)	Any BPM with z=3-83	Human Diagnostics and Therapy	1000 cfm exhaust fan in hot lab for xenon-133
St. Michael's Medical Center, Newark, New Jersey. (29-06759-01)	Any BPM listed in Groups I, II, III of schedule A of 10 CFR 35.100.	Human Diagnostics	Hold-up decay for xenon in meteorological balloon for 10 half-lives
	Any BPM listed in 10 CFR 31.11	In Vitro Studies	
Veterans Administration Hospital, Kansas City, Missouri (24-00496-05)	Various BPM with z=3-83	In Vitro Studies	Fume hood with 30,000 cfm blower
Gradview Hospital Dayton, Ohio (34-06904-01)	Any BPM listed in Groups I, II, III, and IV of schedule A of 10 CFR 35.100.	Human Diagnostics and Therapy	Activated charcoal traps with 95% removal efficiency for xenonal
	Any BPM listed in 10 CFR 31.11.	In vitro studies	
Veterans Administration Hospital, Oklahoma City, Ok. (35-00526-04)	Any BPM z=3-83, molybdenum-99, sealed strontium sources.	Human Diagnostics and Therapy Technetium-99m generator	Fume hood
Rhode Island Hospital Providence, Rhode Island, (38-01763-01)	Any BPM with z=1-83 (excluding alpha emitters)	Research	Incinerator equipped with wet scrubbers

Notes:
a) z = atomic number
b) specific amendments to licenses are not necessarily included
c) total amounts allowed for each licensee vary widely
d) source of information for table is from each individual license file

High Energy Accelerators

High energy accelerators are large electronic devices designed to accelerate electrons, protons, positrons or other subatomic particles to high levels of energy for use in bombarding target atomic nuclei. There are two basic types of high energy accelerator geometries currently in use in the United States, namely the linear and circular types. Higher energies are obtained through the use of colliding beam equipped accelerators. The colliding beam equipped accelerators utilize storage principles for the recycling of beam particles.

The principal airborne radioactive emissions at high energy accelerators are activation products of air and dust. Some of these radionuclides (and half-lives) are ^{41}Ar (1.83 hrs), ^{24}Na (15 hrs), ^{15}O (124 sec), ^{13}N (10 min), ^{11}C (20.5 min), ^{7}Be (53 days), and tritium (12.3 yrs). The principal control technology utilized at high energy accelerators is hold-up confinement prior to release which permits the decay of the short-lived radionuclides.

The Department of Energy currently operates numerous accelerators in research programs. Three of the four largest existing high energy accelerators are the Alternating Gradient Synchrotron (33GeV) at Brookhaven National Laboratory, Fermi Accelerator (400 GeV) at the Fermilab in Batavia, Illinois, and the Stanford Linear Accelerator (20 GeV) at Stanford University. The fourth accelerator is the Zero Gradient Synchrotron (12GeV) at Argonne National Laboratory which is presently being phased out and will be decommissioned in the near future. Two relatively large high energy accelerators under construction are the Positron-Electron Storage Ring Project (PEP) located at Stanford University, and the Isabelle Proton-Proton Storage Facility at Brookhaven National Laboratory. These five accelerators and their airborne emission control technologies are examined below (4-26 through 4-29).

Alternating Gradient Synchrotron (AGS)
Brookhaven National Laboratory (BNL)

The AGS, which is illustrated in Figure 4.1, is a proton accelerator where the particles are initially accelerated by a Cockroft-Walton generator which brings the particles up to 750 KeV. The particles are further energized in a 200 MeV linear accelerator and finally introduced into the circular AGS. The main accelerator ring consists of a vacuum chamber surrounded by 240 magnets where the particles are finally accelerated up to 33 GeV energies.

Most of the air that is activated during accelerator runs is recirculated within the ring tunnel in a relatively closed system. An exception to these closed conditions are the short air gap at the Chemistry Linac Irradiation Facility (CLIF) (see Figure 4.1) which is vented by an exhaust fan at the ground level, and the cave surrounding the fast-beam line in the northern experimental area which is vented only after each run. The air gap at the CLIF has an exhaust stream with a total radioactivity concentration of 0.27 pCi/l with a release rate of 0.028 Ci/uA-hr. The release from the fast-beam line cave includes approximately 0.14 Ci per venting with an annual discharge of 1.7 Ci of short lived radionuclides. A venting of 0.77 Ci of ^{7}Be annually is reported from these two locations (4-26).

Fermilab Accelerator, Batavia, Illinois

The Fermilab accelerator is a proton synchrotron with energy level generally exceeding 400 GeV. The primary control of airborne radioactive emissions is hold-up confinement. Emissions include ^{11}C, ^{24}Na and tritium. Effluent totals for 1976 included 340 mCi of tritium, 4000 Ci of ^{11}C, and 10 mCi of particulates (primarily ^{24}Na) (4-27).

Stanford Linear Accelerator (SLAC), Stanford University

The SLAC facility contains a two mile long linear accelerator capable of attaining up to 20 GeV energy levels. The accelerator and

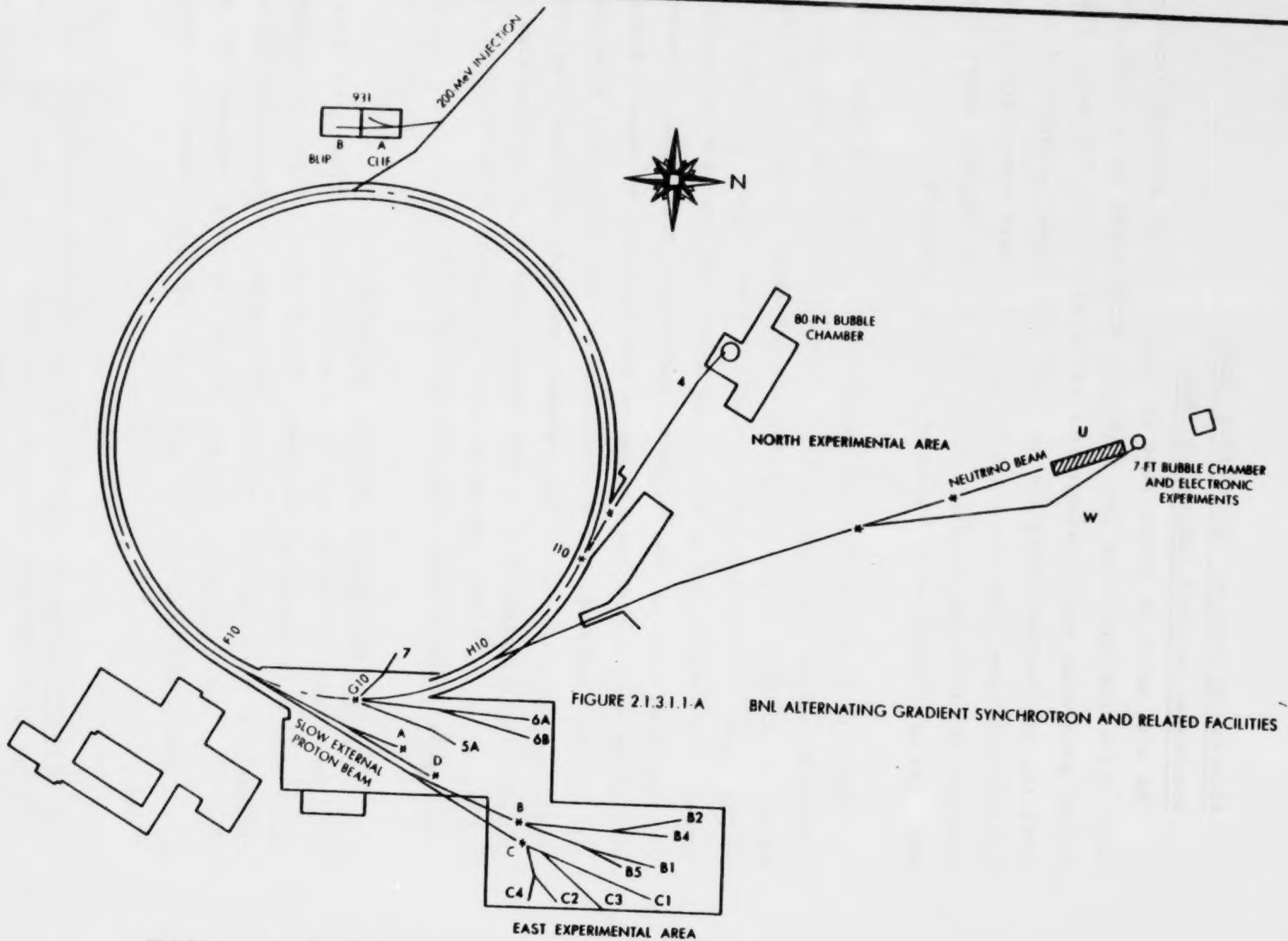

200 MeV INJECTION
911
B
A
BLIP
CLIF
N
80 IN BUBBLE CHAMBER
4
NORTH EXPERIMENTAL AREA
U
NEUTRINO BEAM
7-FT BUBBLE CHAMBER AND ELECTRONIC EXPERIMENTS
W
110
F10
H10
G10
7
6A
6B
5A
A
D
SLOW EXTERNAL PROTON BEAM
B
C
B2
B4
B5
B1
C4
C2
C3
C1
EAST EXPERIMENTAL AREA

FIGURE 2.1.3.1.1-A BNL ALTERNATING GRADIENT SYNCHROTRON AND RELATED FACILITIES

BNL ALTERNATING GRADIENT SYNCHROTRON AND RELATED FACILITIES

Source: Reference 4-26

DAMES & MOORE

FIGURE 4.1

the beam switchyard (BSY) areas, which are not normally vented while the electron beam is on, are vented by twelve fans; the discharge point is just slightly above the roof elevation. The exhaust rates for the accelerator and BSY are 60 and 40 m^3/second, respectively. Gaseous release is delayed (time period unspecified) following each accelerator run. Each exhaust fan is coupled with a Geiger-Mueller detector to aid in proper delay control. In 1976, the total release of short-lived gaseous radioactivity from the facility was 0.052 curies (4-28).

Positron-Electron Storage Ring Project (PEP) Stanford University

The PEP is a large storage ring accelerator scheduled for completion in 1980. The PEP will be located at the eastern end of the SLAC and will utilize particles from SLAC. The design capacity of the PEP is 30 GeV for electrons and 15 GeV for protons. Only a small fraction ($<10^{-5}$) of the total SLAC power will be delivered to PEP during regular operation. For this reason, it is believed that the activation product release will be substantially lower than that of SLAC and thus hold-up is not deemed necessary (4-28).

Isabelle Facility, Brookhaven National Laboratory

The proposed Isabelle Proton-Proton Storage Accelerator facility will consist of two magnet rings which will supply the focusing and bending fields for counter rotating proton beams. The Isabelle is designed to generate up to 400 GeV beam energies. The overall shape of the facility is circular with six symmetrically placed straight segments interspersed. The loading of the storage rings will occur once daily and will be supplied by the existing 33 GeV Alternating Gradient Synchrotron (4-29). Hold-up confinement will be the probable control technology at the facility for air activation products. The short-lived radionuclides in the facility airborne effluent are expected to be about 6×10^{-4} Ci/sec (4-29).

Fusion Energy Devices

Fusion energy research in the United States is in the scientific feasibility stage proceeding toward the engineering feasibility stage. Demonstration of the scientific feasibility of fusion energy requires building an experimental device in which a combination of temperature, fuel density, and confinement time are sufficient to yield a net output of energy from the device.

There are presently two distinct research efforts being pursued to establish the scientific feasibility of fusion energy: magnetic confinement and inertial confinement. The magnetic confinement approach utilizes magnetic fields to confine hot (expected to be around 100,000,000°K) ionized gas (plasma) so that the plasma does not react with the walls of the fusion chamber. Inertial confinement employs high intensity laser or particle beams to implode and heat a small deuterium-tritium pellet. Currently, the published literature on inertial confinement is limited by the classified nature of much of the work. There is somewhat more information available on the various versions of the magnetic confinement approach. The work presently receiving the most attention is the torodial magnetic confinement employed in "tokamak" reactors. Tokamak research in the United States is currently going on at several universities including Princeton University and the University of Wisconsin, and at the Oak Ridge National Laboratory. Mirror magnetic confinement research is currently being performed at Lawrence Livermore Laboratory. Theta-pinch magnetic confinement research is being formed by research teams from Los Alamos Scientific Laboratory and Argonne National Laboratory.

The principal airborne radioactive effluents in both these approaches are estimated to be tritium and the air activation products including ^{41}Ar, ^{16}N, and ^{13}N. Information on the radioactive airborne emission control technology on the existing facilities could not be obtained. However, the planned Tokamak Fusion Test Reactor

(TFTR) at the Princeton Plasma Physics Laboratory (PPPL) at Princeton University will include systems for the control of airborne radionuclide emissions, and this facility is examined below (4-31).

Air flow at the TFTR will be controlled through pressure zonation. The test cell (the minimum pressure zone) will have a pressure of 0.3 inches water gauge below that of atmospheric pressure, and the air from the test cell will be vented to the atmosphere by way of the general heating-ventilation-air conditioning (HVAC) system. The HVAC system will consist of centrifugal supply fans with inlet vanes, steam pre-heat coils, chilled water coils, a steam humidifier, and air filters. The system has a normal discharge rate of 15,000 cfm and will provide three air changes per hour. The purging mode of the HVAC has a discharge rate of 46,620 cfm.

Once the operation begins, the principal airborne radioactive effluent from the TFTR will be tritium. All tritium bearing gaseous streams will be passed through several clean-up systems before discharge to the atmosphere. It is estimated that about 70-80 Ci/year will be released. Activation of air within the test cell will result in the formation of short-lived radionuclides including ^{41}Ar, ^{16}N, and ^{13}N which will be vented to the atmosphere via the HVAC system. The TFTR tritium clean-up systems, which are examined below, will be the Tritium Storage and Delivery Clean-up System, the Torus Clean-up System, the Tritium Vault Clean-up System, and the Test Cell Emergency Recirculation and Tritium Clean-up System. During each D-D pulsing, an estimated 5 to 50 mCi of tritium will be generated. Tritium from the D-D pulsing will be sent to the Torus Vacuum Clean-up system.

The functions of the Tritium Storage and Delivery Cleanup Systems (TSDCS) will be to reduce the tritium releases to the tritium vault and to the environment, to maintain a dry, inert atmosphere in the system glove box, and to maintain a negative pressure in the glove box. The TSDCS will process the argon atmosphere of the glove box and will provide five glove box volume changes per hour. Tritium will be converted to tritiated water vapor with a conversion efficiency of 99.9%. The tritiated water vapor will be adsorbed with an adsorption efficiency of 99.9%. The TSDCS will also reduce oxygen concentrations in the glove box argon stream to below 10 ppm. The TSDCS system will consist of blowers, a preheater, a catalytic recombiner, a Cu-CuO oxygen getter, a cooler, and molecular sieve beds. The catalytic recombiner will combine any gaseous tritium present with oxygen to form tritiated water vapor. The oxygen getter will be used to remove oxygen from the glove box atmosphere because of the pyrophoric nature of the uranium beds used for tritium storage. The tritiated water vapor will be removed by the molecular sieve absorbent beds. Two blowers with 10 scfm capacities operated by a 1 horsepower engine will be used. The oxygen getter will be a regenerable Cu-CuO getter with a design temperature of 350°F and a capacity of 10 scfm. The air cooler will have a capacity of 10 scfm and will reduce gaseous stream temperature down to 70 to 80°F. The two molecular sieve beds will be of the disposable type.

The functions of the Torus Clean-up System (TCS) include cleanup of the tritium receiving glove box and utility glove box, clean up of the exhaust gas from the Torus and Neutral Beam vacuum pumping system, maintenance of negative pressure and clean up of leaks from the Torus and neutral beam vacuum systems, reducing the tritium releases to the environment from the vacuum vessel and cooling system during discharge cleaning, and to provide backup to the TSDCS. The TCS will operate in both the Holdup-Process Mode (HPM) and the Direct-Process Mode (DPM). The HPM will use gas holding tanks for gaseous stream collection and will receive input from the torus and neutral beam pumping system, the purge of the TSDCS, and the vacuum vessel and cooling system during discharge cleaning. Gaseous streams will be pumped from the holding tanks at 2 scfm into a 50 scfm nitrogen stream. The stream is then passed through a preheater, a catalytic recombiner, an air cooler, and a regenerable dessicant bed.

The functions of the Tritium Vault Clean-up System (TVCS) will be to clean up the atmosphere of the tritium vault or the holding tank room, maintain the area at negative pressure, maintain negative pressure in the torus or neutral beam in the event of a leak, to further reduce tritium releases, and to serve as backup to TCS. The system will convert tritium gas to tritiated water vapor with a conversion efficiency of 99.9% and will then adsorb the water vapor with an efficiency of 99.9%. This system will have a volume capacity of 1000 scfm and will consist of two blowers, a preheater, a catalytic recombiner (Pt/Pd), an air cooler, and an adsorbent bed of molecular sieves.

The function of the Test Cell Emergency Recirculation and Tritium Cleanup System will be to cleanup the test cell in the event of a tritium release. The system consists of blowers, adsorbents, and a condenser and is designed to remove at least 90% of the initial tritiated water vapor released during an accident and to condense at least 40% of the moisture passing through the HVAC cooling coils.

Weapons Production Facilities

Currently, there exists several facilities in the United States associated with nuclear weapons production and/or testing, some of which are owned and operated by the Department of Energy (DOE). However, the paucity of published unclassified documents precludes extensive discussion of radioactive airborne emissions control technology. The existing facilities include the Mound Laboratory at Miamisburg, Ohio; Pantex Plant at Amarillo, Texas; Pinellas Plant at St.Petersburg, Florida; and Rocky Flats Plant at Jefferson County, Colorado. The following information on these facilities comes mainly from the ERDA (now DOE) summary document on environmental monitoring at DOE contractor sites (4-33 through 4-36).

Mound Laboratory - Miamisburg, Ohio

The Mound Laboratory has been operated since 1949 and the operations at the laboratory include research, development, engineering, and production of components for the DOE weapons program. In addition, the laboratory performs fabrication of ^{238}Pu heat sources, and the separation and purification of stable noble gas isotopes. The laboratory is currently operated by the Monsanto Research Corporation. The principal effluent radionuclides at Mound Laboratory are tritium and ^{238}Pu. The control technologies employed at the facility include pressure zonation and HEPA filters. The exhausts of glove boxes have HEPA filters and just prior to stack discharge there are two banks of HEPA filters. In 1976, the radioactive airborne effluent consisted of 6206 Ci of tritium and 0.015 mCi of ^{238}Pu.

Pantex Plant - Amarillo, Texas

The Pantex Plant activities include atomic weapons assembly, stockpile surveillance and retirement, as well as chemical high explosives fabrication, and testing. The plant is operated by the Mason & Hanger - Silas Mason Co., Inc. for the DOE. There is no continuous release of airborne radioactive effluents from the Pantex

Plant. Nearly all of the radioactive materials handled at the Pantex Plant are in sealed containers. Information on airborne emission control technologies could not be obtained. The estimated atmospheric releases of radioactive materials from the Pantex Plant in 1976 were 0.01 Ci of tritium, 40 mCi of depleted uranium (^{238}U), and virtually no plutonium.

Pinellas Plant - St. Petersburg, Florida

The Pinellas Plant activities include the design, development and manufacture of special electronic and mechanical nuclear weapons components. The site is operated by the Neutron Devices Department of the General Electric Company for the DOE. Information on the airborne emission control technology at the Pinellas Plant could not be obtained. In 1976, 80.59 Ci of tritium gas, 114 Ci of tritium in water vapor, and 19.9 curies of ^{85}Kr were released from the main stack. In addition, releases from the laboratory stack during 1976 included 61.76 Ci of tritium in water vapor, and 20.31 curies of tritium gas.

Rocky Flats Plant - Jefferson County, Colorado

The Rocky Flats Plant activities include the fabrication of weapons components from plutonium, uranium, beryllium and stainless steel. The plant is operated for the DOE by Rockwell International. All exhaust from the plutonium facilities at Rocky Flats is passed through multistage HEPA filters which are designed to permit in-place DOP testing of all stages. The reported atmospheric releases for the Rocky Flats Plant for 1976 included about 3.724 uCi of plutonium, 27.67 uCi of uranium, and 1.159 curies of tritium.

National Laboratories

There are several major national laboratories in existance that are operated for the Department of Energy (DOE) by various private companies. These laboratories include Oak Ridge National Laboratory (ORNL) located at Oak Ridge, Tennessee; Savannah River Plant (SRP) located near Barnwell, South Carolina; Idaho National Engineering Laboratory (INEL) located near Idaho Falls, Idaho; Los Alamos Scientific Laboratory (LASL) located at Los Alamos, New Mexico; Hanford Reservation located near Richland, Washington; Argonne National Laboratory (ANL) located near Chicago, Illinois; and Brookhaven National Laboratory (BNL) located at Upton, New York. These laboratories contain many facilities which perform a substantial amount of work involving radioactive materials.

The airborne emission control technology of the facilities at one major national laboratory (INEL) was examined in detail and is presented below. Also presented is a review of the airborne emission control technologies at some of the facilities at other laboratories including Hanford Reservation, LASL, and BNL. The airborne emission control technologies of the facilities at national laboratories not examined are similar to those examined below.

Idaho National Engineering Laboratory (INEL)

The INEL was established in 1949 to build, test, and operate nuclear reactors and the supporting facilities for these operations. It is located on the Snake River Plain in Idaho near Idaho Falls and is still operating. There are four major DOE contractors which currently operate facilities at INEL. These contractors and the major facilities they operate are (4-37):

EG&G Idaho, Inc.:
Test Reactor Area (TRA),
Test Area North (TAN),
Power Burst Facility (PBF),
Auxiliary Reactor Area (ARA),

Allied Chemical Corporation:
Idaho Chemical Processing Plant (ICCP).

Argonne National Laboratory West:
Experimental Breeder Reactor No.2 (EBR-II)
Transient Reactor Test Facility (TREAT)
Hot Fuel Examination Facility (HFEF)
Zero Power Plutonium Reactor (ZPPR)
Laboratory and Office Complex (L&O)

Westinghouse Electric Corporation:
Naval Reactor Facility (NRF).

These facilities and the associated airborne emission control technologies are reviewed below. Data on capital costs for installation of the control technologies and annual operating costs could not be obtained. A discussion of capital costs for HEPA filter systems is provided in Appendix IIA. System specific efficiencies, annual residuals and airborne effluents of the facilities are given where available.

Test Reactor Area (TRA):

The TRA includes the Materials Testing Reactor, the Engineering Test Reactor which is a high-flux test reactor, the Advanced Test Reactor which is a 250 MW(th) test reactor, three low-power reactors, and support (laboratory) facilities. Air flow at all facilities is controlled through pressure zonation. All laboratory exhaust air is passed through dampers, HEPA filters and blowers. Caustic scrubbing of the exhausts from laboratories which use acidic materials is also utilized. All reactor ventilating air is discharged through a 250-ft-high stack. A summary of the airborne effluents from TRA for 1974 is given in Table 4-7.

Test Area North (TAN):

The TAN complex includes the Loss of Fluid Test (LOFT) facility, the Low Power Test (LPT) reactor, the Experimental Beryllium Oxide Reactor (EBOR), and the TAN Support Facilities (TSF). The LOFT facility is the only reactor in operation at the TAN complex. The TSF was originally constructed to support the Aircraft Nuclear Propulsion program. In recent years TSF has devoted much of its operational time for fabrication and assembly of the LOFT Mobile Test Assembly which is a dolly mounted reactor system capable of simulating a wide spectrum of primary coolant disruption scenarios. The LOFT reactor can operate at 55 MW thermal power.

Air flow at TAN Support Facilities (TSF) is controlled through pressure zonation. In zones of high potential contamination, HEPA filters are installed in the effluent ducting to remove particulates. Many of the exhausting ducts also include dampers. At the LOFT, there exists two systems: one for the heating and ventilation air from the containment vessel which includes the off-gas from the blow-down tank, and the other for the heating and ventilation air from the control, equipment, and service buildings. Both systems include roughing filters, HEPA filters, and charcoal adsorbers. In addition the off-gas from the blow-down tank is passed through a moisture separator.

During 1974, the radioactive effluents from TSF were about 1 mCi which was composed of unidentified beta-gamma activity with trace quantities of ^{60}Co, ^{134}Cs, ^{137}Cs, ^{106}Ru, ^{90}Sr, and ^{90}Y. Expected effluents from LOFT are given in Table 4-8.

TABLE 4-7

Test Reactor Area Airborne Waste Summary for 1974*

Nuclide	Curies	Percentage of Total	Half-Life
Argon-41	3980	14.8	1.8 hr
Barium-139	509	1.9	83 min
Cesium-138	44	0.2	32.2 min
Krypton-85m	1273	4.7	4.4 hr
Krypton-87	4245	15.7	76 min
Krypton-88	3644	13.5	2.8 hr
Krypton-89	550	2.0	3.2 min
Rubidium-88	45	0.2	17.7 min
Rubidium-89	8	0.03	15.2 min
Xenon-133	571	2.1	5.3 day
Xenon 135	3952	14.7	9.2 hr
Xenon-135m	1708	6.3	16 min
Xenon-138	6432	23.8	14.2 min

---

* Source : Ref 4-37

TABLE 4-8

Estimated Airborne Radioactivity Releases from LOFT Experiments*

		Estimated Activity Release (Ci/yr)	
Isotope(s)	Radioactive Half-Life	Leakage from Containment	Controlled Release from Vessel Cleanup System
Xenon-133	5.3 day	130	360,000
Xenon-135	9.2 hr	138	110,000
Krypton-85	10.8 yr	0.076	220
Total noble gas		1,350	470,000
Strontium-90	28 yr	0.0058	0.0005
Cesium-137	30 yr	0.0058	0.0005
Iodine-131	8.1 day	6.4	0.1
Other Iodine Isotopes	21 hr (Maximum)	63	0.35
Tritium	12.3 yr	0.00025	5

---

* Source : Ref 4-37.

Power Burst Facility (PBF):

The PBF is a water cooled uranium oxide fueled reactor which is designed to provide information for the DOE Light-Water Reactor safety program.

The principal source of radioactive effluents at PBF is the closed test loop that penetrates into the reactor. Radioactive noble gases produced during reactor operation are trapped either in the closed test loop pressurizer or the knockout drum, and are available to be containerized for storage or processing. Airflow at the facility is controlled through pressure zonation. All exhaust streams are passed through the exhaust room plenum where they pass through roughing (throwaway) filters, followed by HEPA filters and iodine absorption beds. The iodine adsorption beds, which have an efficiency of 99%, are silver zeolites employed because of their high efficiency, fire resistance, radiation-damage resistance, and affinity for organic iodines. Estimated annual system effluents are given in Table 4-9.

Auxiliary Reactor Area (ARA):

The ARA at the present time contains no operating reactors. All former reactors have been removed or dismantled.

The principal sources of radioactive airborne emissions at ARA are the ARA-I hot cells. The hot cells are shielded work areas utilized for radioactive test specimens. The exhaust air from the hot cells is passed through roughing filters, HEPA filters and blowers. One cell is also equipped with charcoal filters. During 1974, no detectable quantities of airborne radioactivity were released from the ARA.

TABLE 4-9*

Postulated Annual Releases of Radioactive Gases from Power Burst Facility[a]

Radionuclide	Maximum No. of Curies Released in one year[b]	Radionuclide Half-Life
Krypton-85	100	10.8 yr
Krypton-87	9,500	76 min
Krypton-88	13,000	2.8 hr
Xenon-133	5,500	5.3 day
Xenon-135	20,000	9.2 hr
Argon-41	290	1.8 hr
Tritium	2.6	12.3 yr
Iodine-131	0.045	8.1 day
Iodine-132	0.13	2.3 hr
Iodine-133	0.38	21 hr

(a) Assumes 5% of the noble gases and 0.0001% of the iodines released to the atmosphere from 200 preirradiated fuel rods over 1 year (20 tests with preirradiated rods per year and 10 rods fail per test).

(b) No credit has been taken for radioactive decay during holdup in the experimental loop.

---

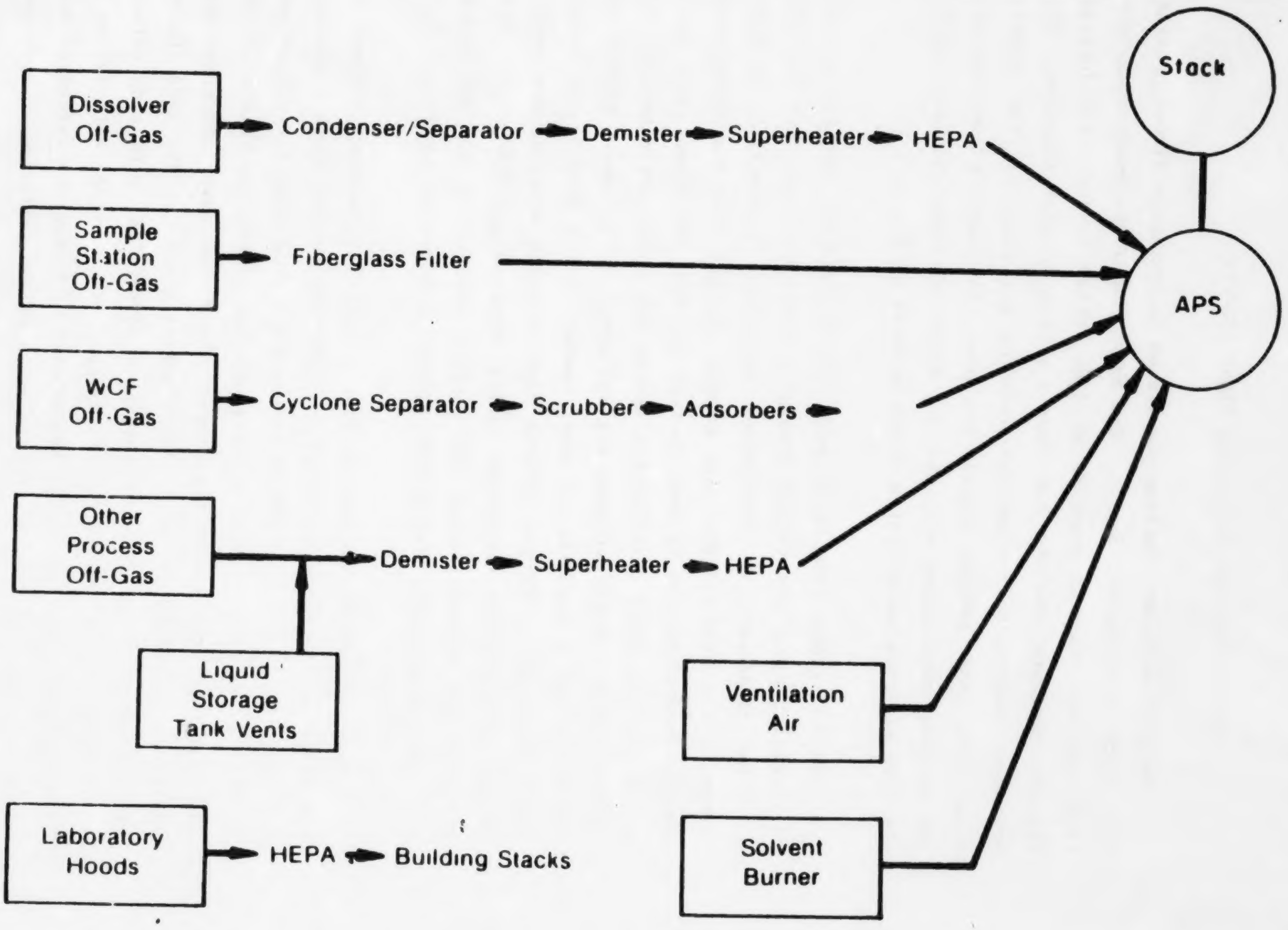
* Source : Ref 4-37

Idaho Chemical Processing Plant (ICPP):

The ICPP is a reprocessing plant used to recover enriched uranium from spent (irradiated) fuels. The spent fuels processed originate from test and research reactors at INEL, other domestic and foreign research reactors, and the U.S. Navy's ship propulsion reactors. The principal sources of radioactive airborne emissions are the process dissolvers, other process vessels and areas, the waste solvent burner, the process ventilating air, and the Waste Calcining Facility (WCF). The ICPP airborne waste system is illustrated in Figure 4.2.

The off-gases associated with the dissolution portion of the reprocessing cycle are routed through a cleanup system that includes a reflux condenser, an entrainment separator, a demister, a super heater, and a HEPA filter. All gaseous streams from the dissolution process except one can be sent through the Rare Gas Plant (RGP) which contains a cryogenic distillation system for noble gas removal. The other process off-gas streams are collected by a common header and passed through a demister, a super heater, and a HEPA filter before stack discharge. Off-gas streams from sampling stations are passed through a fiberglass (roughing) filter before stack discharge. Off-gas from the solvent burner and process ventilating air are routed into the Atmospheric Protection System illustrated in Figure 4.3.

The Atmospheric Protection System (APS) is located adjacent to the stack and provides the final air cleaning before stack discharge. For ventilation air, the system includes a 7 foot deep fiberglass pre-filter in series with HEPA filters and the system can handle 150,000 cfm from the various ICPP buildings. The 7 foot deep fiberglass pre-filter is contained within a buried concrete vault. The HEPA filters are contained in 26 caissons installed in parallel with each caisson containing 4 HEPA filters. The caissons are provided with valves to isolate sectors during filter replacement. A separate system of deep bed prefilters and HEPA filters is employed for filtering of hydrogen-

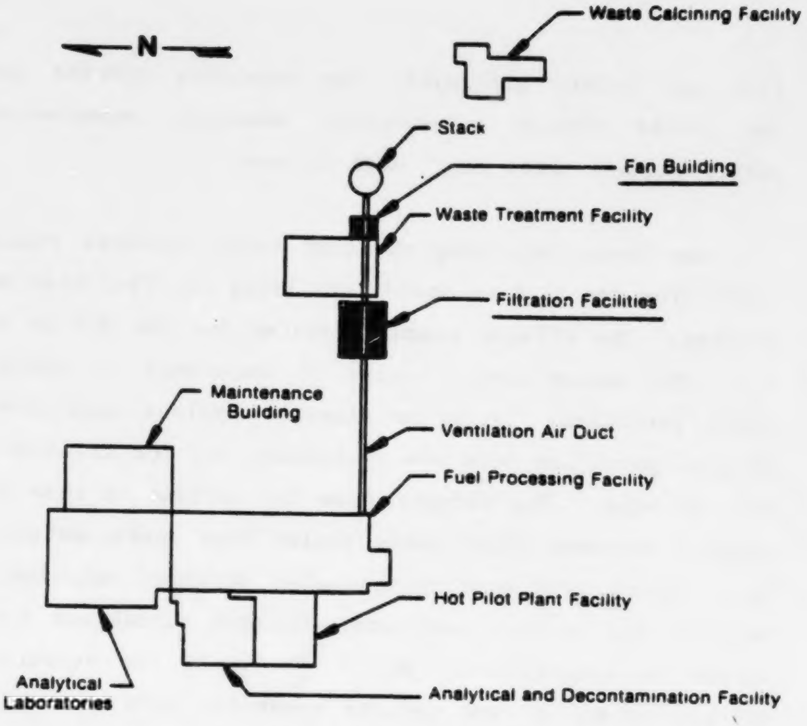

Dissolver Off-Gas
Condenser/Separator
Demister
Superheater
HEPA
Sample Station Off-Gas
Fiberglass Filter
WCF Off-Gas
Cyclone Separator
Scrubber
Adsorbers
Other Process Off-Gas
Demister
Superheater
HEPA
Liquid Storage Tank Vents
Laboratory Hoods
HEPA
Building Stacks
Ventilation Air
Solvent Burner
Stack
APS

ICPP AIRBORNE WASTE SYSTEM

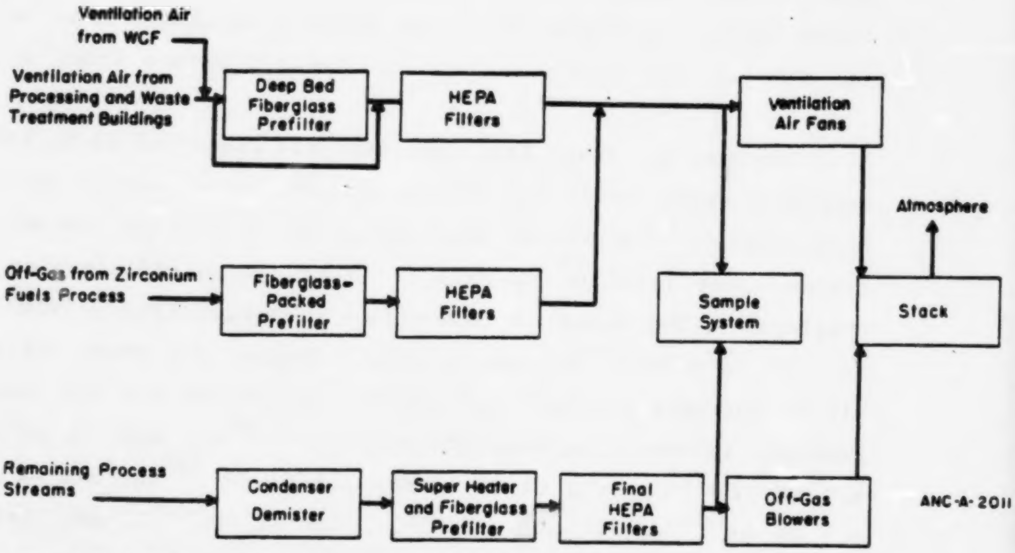
Source: Reference 4-37

DAMES & MOORE

FIGURE 4.2


N
Waste Calcining Facility
Stack
Fan Building
Waste Treatment Facility
Filtration Facilities
Maintenance Building
Ventilation Air Duct
Fuel Processing Facility
Hot Pilot Plant Facility
Analytical Laboratories
Analytical and Decontamination Facility

(A) LOCATION OF ATMOSPHERIC PROTECTION SYSTEM AT ICPP


Ventilation Air from WCF
Ventilation Air from Processing and Waste Treatment Buildings
Deep Bed Fiberglass Prefilter
HEPA Filters
Ventilation Air Fans
Atmosphere
Off-Gas from Zirconium Fuels Process
Fiberglass-Packed Prefilter
HEPA Filters
Sample System
Stack
Remaining Process Streams
Condenser Demister
Super Heater and Fiberglass Prefilter
Final HEPA Filters
Off-Gas Blowers
ANC-A-2011

(B) ATMOSPHERIC PROTECTION SYSTEM FLOW DIAGRAM

ATMOSPHERIC PROTECTION SYSTEM

Source: Reference 4-37

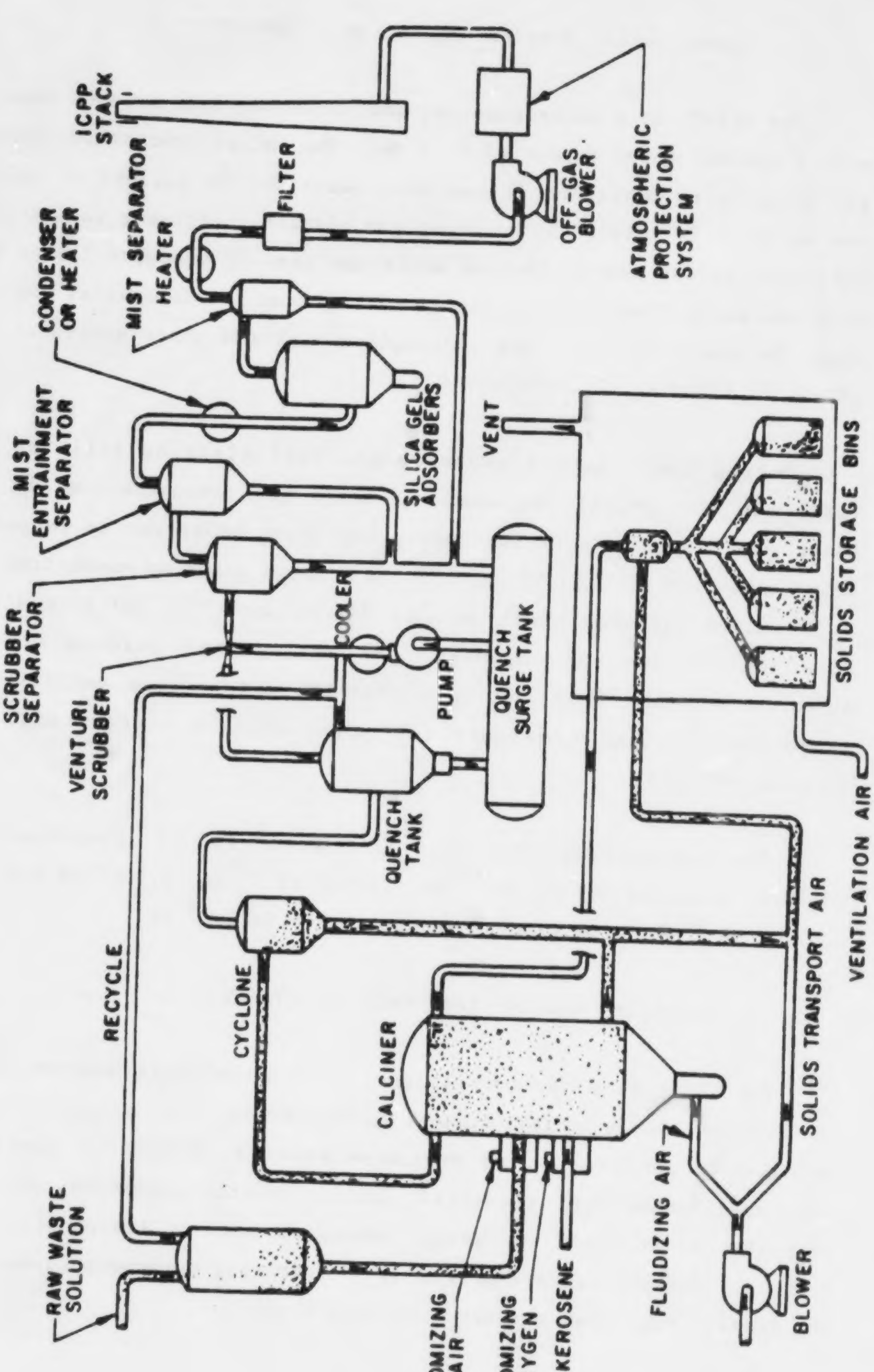
DAMES & MOOR

FIGURE 4.3

rich and acidic off-gases. The remaining process gaseous streams are passed through a condenser, demister, superheater, fiberglass prefilter, and three final HEPA filters.

The Waste Calcining Facility (WCF) converts radioactive liquid waste from the ICPP to solids utilizing the fluidized bed calcination process. The off-gas cleaning system for the WCF is shown in Figure 4.4. The system uses a series of components to remove progressively finer particles. A 60-cm diameter cyclone separates the produced calcine particles from the fluidizing air for transfer to the solids storage bins. The off-gas from the cyclone is then scrubbed with a venturi scrubber after being cooled from approximately 450°C to 75°C in a quench tank containing cooled scrubber solution. The venturi scrubber has an 11.4 centimeter diameter throat and further cools the stream to approximately 68°C. Following the venturi scrubber, the off-gas enters a vane cyclone separator with wire mesh pads, it is reheated in a heat exchanger, and then enters into a silica gel adsorber system for removal of volatile ruthenium isotopes. It is then further heated before entering into three remotely removable filter units, which consist of two 60x75x30 cm HEPA filters in series; and finally the stream is sent to the APS before stack discharge.

The Rare Gas Plant has a recovery efficiency of 25 to 45% and is operating specifically for ^{85}Kr production for industrial and research applications. The overall decontamination factors for the WCF off-gas system range from 10^5 to 5×10^8. Other system efficiencies are not available. The annual system effluents ranged from 1.2×10^6 Ci/year in 1961 to 4.8×10^3 Ci/year in 1973. During 1974 there was a significant increase in fuel reprocessing activities and the radioactive airborne releases included 253,900 Ci of ^{85}Kr, 6036 Ci of tritium, 6.7 Ci of ^{137}Cs, 6.3 Ci of ^{125}Sb, 3.8 Ci of ^{106}Ru, 3.2 Ci of ^{90}Sr, 0.7 Ci of ^{144}Ce, 0.6 Ci of ^{134}Cs, 0.1 Ci of ^{129}I, and less than a total of 0.1 Ci of other radioactivity.


ICPP STACK
CONDENSER OR HEATER
MIST SEPARATOR
HEATER
FILTER
OFF-GAS BLOWER
ATMOSPHERIC PROTECTION SYSTEM
MIST ENTRAINMENT SEPARATOR
SILICA GEL ADSORBERS
VENT
SCRUBBER SEPARATOR
VENTURI SCRUBBER
COOLER
PUMP
QUENCH SURGE TANK
SOLIDS STORAGE BINS
QUENCH TANK
VENTILATION AIR
RECYCLE
CYCLONE
SOLIDS TRANSPORT AIR
CALCINER
RAW WASTE SOLUTION
ATOMIZING AIR
ATOMIZING OXYGEN
KEROSENE
FLUIDIZING AIR
BLOWER

WCF SCHEMATIC FLOWSHEET

Source: Reference 4-37

DAMES & MOORE

FIGURE 4.4

Experimental Breeder Reactor No.2 (EBR-II):

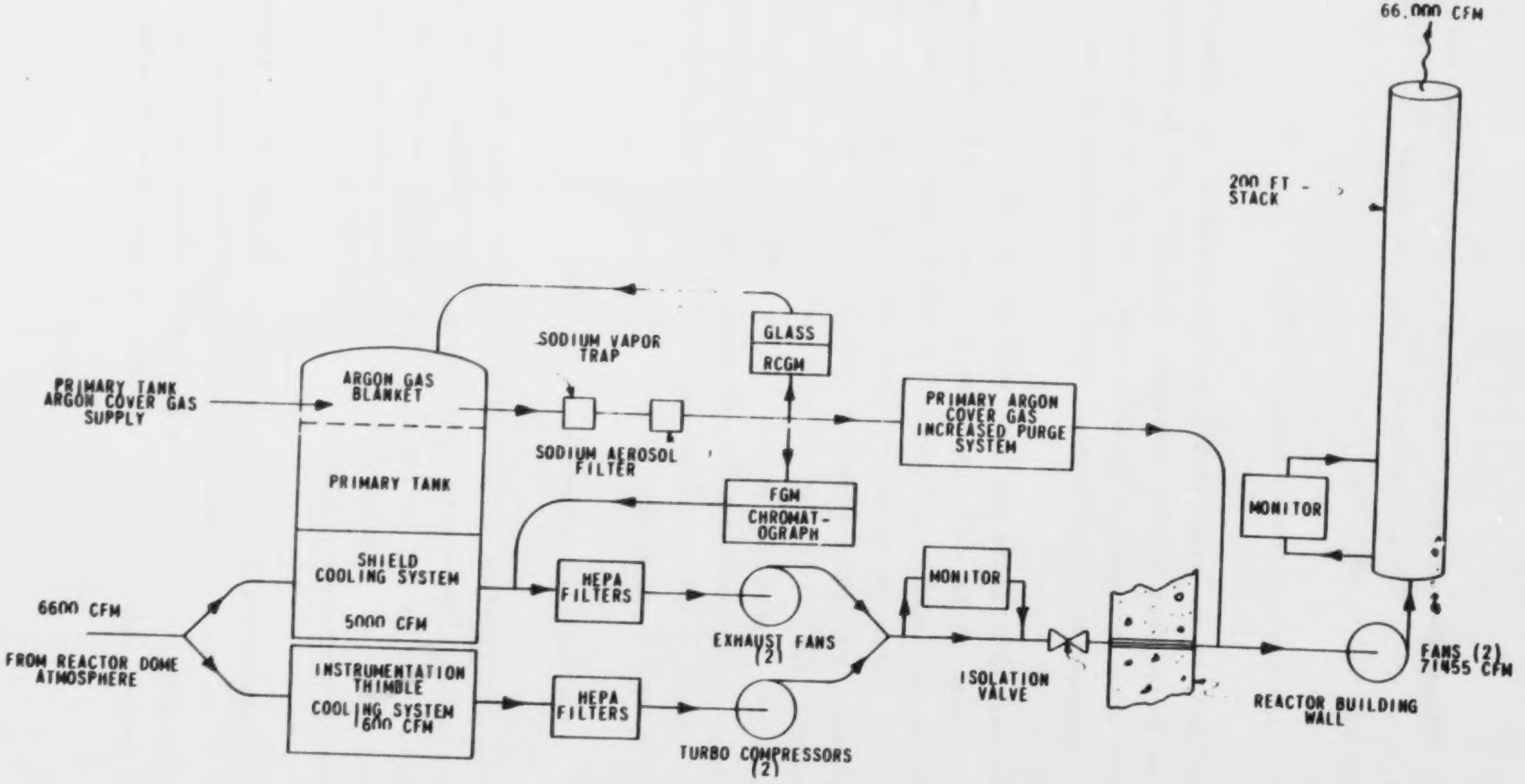
The EBR-II is a heterogeneous, sodium-cooled fast breeder reactor with a thermal power output of 62.5 MW. The entire reactor is submerged in a large container filled with about 90,000 gallons of molten sodium which is covered by an argon gas blanket. Airborne radioactive effluents at the EBR-II include noble gas fission products (xenon and krypton) and activation products resulting from the impurities and the argon in the cover gas. The radioactive airborne waste system at the EBR-II is illustrated in Figure 4.5.

During fuel testing experiments, fuel cladding failures may result in substantial increases in noble gas concentrations in the cover gas. During these instances, the argon cover gas is purged by being exhausted at rate of up to 3 cfm through a sodium vapor trap and a 10 micron sintered metal aerosol filter into the 200 foot stack. HEPA filters are not employed for purging this gaseous stream. Airborne efluents from the fuel assembly and storage building are exhausted through three parallel banks of HEPA filters with six filters per bank.

The radioactive effluents in 3.4×10^9 ft^3 of discharged air in 1974, included 367 Ci of ^{133}Xe, 147 Ci of ^{135}Xe, 0.7 Ci of tritium, 0.07 Ci of ^{82}Br, 0.06 Ci of ^{41}Ar, and 0.005 Ci of ^{85}Kr.

Transient Reactor Test Facility (TREAT):

The TREAT is a reactor designed to produce short extreme pulses of nuclear energy which produce sufficiently high temperatures to permit the performance of meltdown studies of various prototype and experimental fuel elements. During reactor operation, all gaseous streams at TREAT are passed through a bank of six parallel HEPA filters. The streams are driven by two parallel turbo-compressors and are finally exhausted through a 60-foot stack.


66.000 CFM
200 FT STACK
PRIMARY TANK ARGON COVER GAS SUPPLY
ARGON GAS BLANKET
PRIMARY TANK
SHIELD COOLING SYSTEM
5000 CFM
INSTRUMENTATION THIMBLE COOLING SYSTEM 1600 CFM
6600 CFM
FROM REACTOR DOME ATMOSPHERE
SODIUM VAPOR TRAP
SODIUM AEROSOL FILTER
GLASS
RCGM
FGM
CHROMAT-OGRAPH
PRIMARY ARGON COVER GAS INCREASED PURGE SYSTEM
HEPA FILTERS
HEPA FILTERS
EXHAUST FANS (2)
TURBO COMPRESSORS (2)
MONITOR
ISOLATION VALVE
REACTOR BUILDING WALL
MONITOR
FANS (2) 71455 CFM

EBR II RADIOACTIVE AIRBORNE
WASTE SYSTEM - REACTOR PLANT

Source: Reference 4-37

The radioactive efflents from TREAT in 1974 included 148.2 Ci of ^{41}Ar, 0.14 Ci of ^{85}Kr, 0.63 Ci of ^{87}Kr, 0.37 Ci of ^{88}Kr, 0.16 Ci of ^{133}Xe, and 0.07 Ci of ^{135}Xe.

Zero Power Plutonium Reactor (ZPPR):

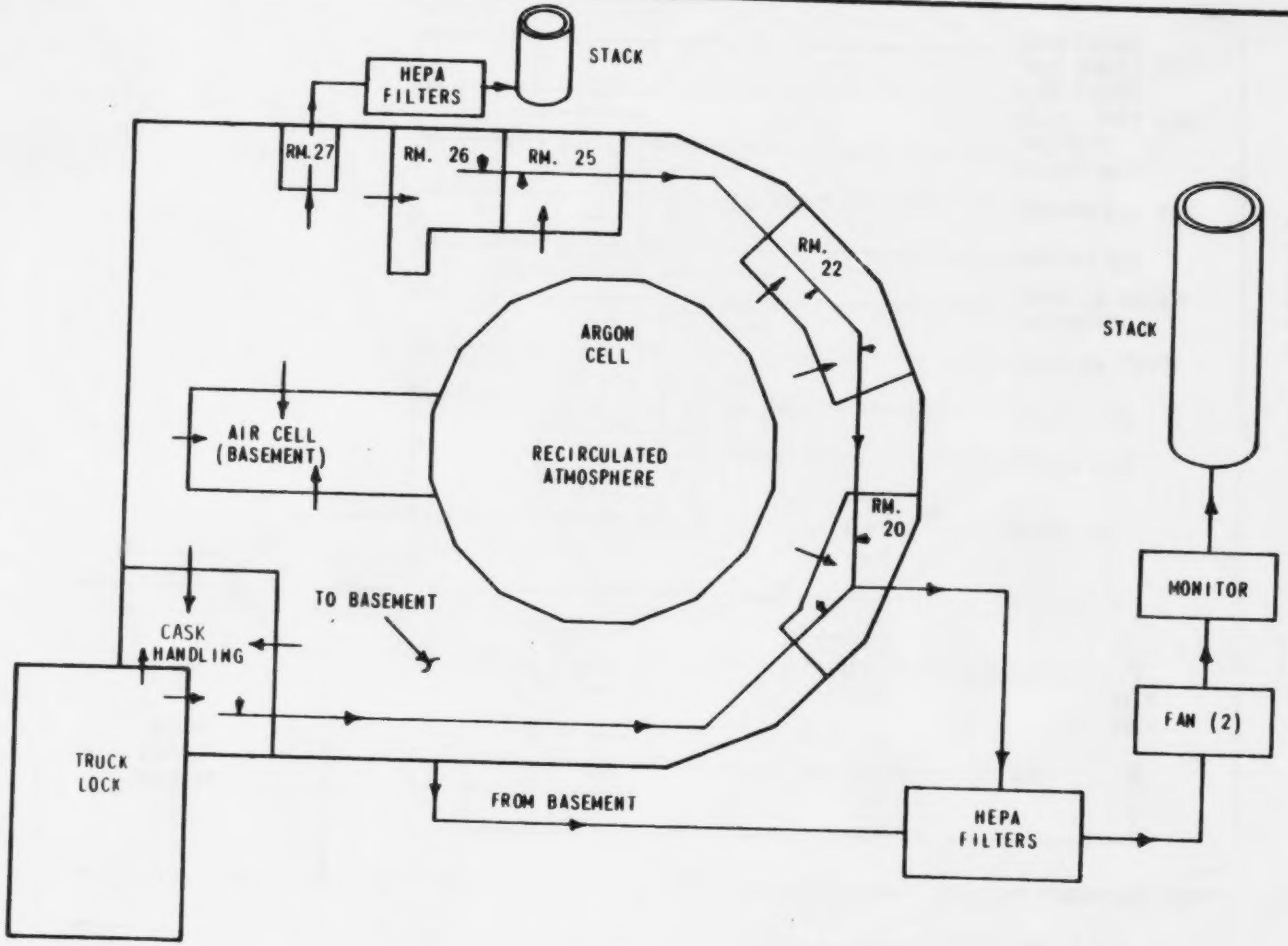
The ZPPR is an experimental reactor designed for research in plutonium fueled fast breeder reactors. The ZPPR cell is enclosed in a 50-foot diameter concrete building with a height of 32 feet. The cell is enclosed within an earthen mound approximately 50 feet high.

The cell roof is filled with sand and gravel to a depth of at least 16 feet. This roof can serve as a particulate filter during abnormal occurrences. Air flow is controlled through pressure zonation. All potentially contaminated gaseous streams are passed through hoods into three banks of HEPA filters. When the reactor is is operating, the cooling air is recirculated through HEPA filters but not exhausted. When the reactor is not operating, the circulation cooling air is discharged after the monitoring sytem has checked the gaseous stream. The effluents in $2.1x10^3$ ft^3 of air discharged in 1974 included 0.17 Ci of xenon-135.

Hot Fuel Examination Facility (HFEF):

The HFEF consists of two buildings: The HFEF-S building activities include disassembly, inspection, and reassembly of subassemblies. The HFEF-N building is used for the interim and final inspection of fast reactor fuel and irradiated structural specimens for the LMFBR research programs.

At both HFEF-N and HFEF-S, which are illustrated in Figures 4.6 and 4.7, air flow is controlled through pressure zonation. Exhaust air from HFEF-S is passed through 36 HEPA filters in parallel before being routed underground to the base of the 200-foot stack. The

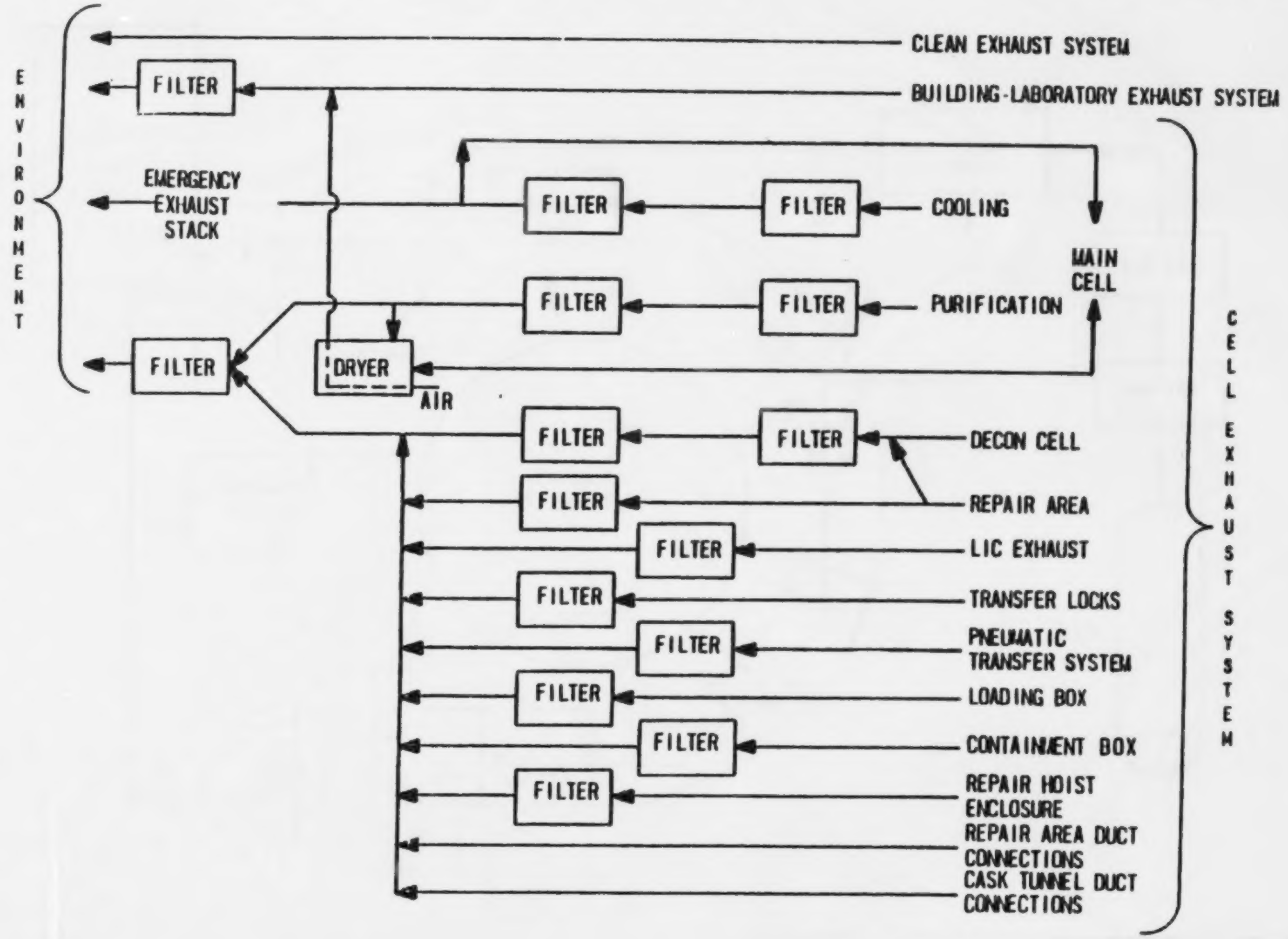

STACK
HEPA FILTERS
RM.27
RM. 26
RM. 25
RM. 22
ARGON CELL
RECIRCULATED ATMOSPHERE
AIR CELL (BASEMENT)
STACK
RM. 20
TO BASEMENT
CASK HANDLING
TRUCK LOCK
FROM BASEMENT
HEPA FILTERS
MONITOR
FAN (2)

HFEF-S VENTILATION FLOW DIAGRAM

Source: Reference 4-37

DAMES & MOORE

FIGURE 4.6


CLEAN EXHAUST SYSTEM
BUILDING-LABORATORY EXHAUST SYSTEM
ENVIRONMENT
FILTER
EMERGENCY EXHAUST STACK
FILTER
FILTER
COOLING
MAIN CELL
FILTER
FILTER
PURIFICATION
FILTER
DRYER
AIR
FILTER
FILTER
DECON CELL
FILTER
REPAIR AREA
FILTER
LIC EXHAUST
FILTER
TRANSFER LOCKS
FILTER
PNEUMATIC TRANSFER SYSTEM
FILTER
LOADING BOX
FILTER
CONTAINMENT BOX
FILTER
REPAIR HOIST ENCLOSURE
REPAIR AREA DUCT CONNECTIONS
CASK TUNNEL DUCT CONNECTIONS
CELL EXHAUST SYSTEM

HFEF-N CELL VENTILATION SYSTEM

SOURCE: REFERENCE 4-37

DAMES & MOORE

FIGURE 4.7

plutonium glove box exhaust is vented through 3 HEPA filters. The room containing the glove box contains its own exhaust system with HEPA filter. All exhaust air at HFEF-N is passed through 30 HEPA filters.

In 1974, HFEF-S discharged 1.2 Ci of xenon-133, and HFEF-N had no significant (above minimum detection levels) emissions.

Laboratory and Office Complex (L&O):

The L&O complex contains the support facilities for the Argonne National Laboratory - West operations. These facilities include laboratory and office buildings, waste treatment buildings and facilities, and storage facilities. Air flow at all facilities is controlled through pressure zonation. The exhaust air from hoods and work areas in the laboratory and office buildings are passed through 20 HEPA filters in parallel and discharged through the central 200 foot stack. The exhaust system at the sodium chemistry laboratory includes 12 HEPA filters in parallel and discharges through a short stack. A special sodium sample handling laboratory exhausts directly to the atmosphere after passing through 4 HEPA filters in parallel.

Naval Reactors Facility (NRF) :

The Naval Reactors Facility (NRF) contains the Expended Core Facility (ECF) and three naval reactor prototypes namely the S1W Nautilus prototype, the A1W Enterprise prototype and the S5G submarine prototype. Air flow is controlled through pressure zonation. At the ECF where reactor fuel is handled all exhaust air is passed through the HEPA filters. Gaseous radioisotopes are generally retained until the coolant systems are drained or sampled.

During 1974, the radioactive airborne effluents were less than 0.2 millicuries of particulate emissions, 2 Ci of krypton-85, and 0.11 millicurie of argon-41.

Hanford Reservation - Richland, Washington

The Hanford Reservation occupies about 570 square miles of land along the Columbia River in the southeastern portion of the state of Washington. The Hanford Reservation was set aside by the Army Corps of Engineers during World War II for the Manhattan Engineering Project. Activities at the Hanford Reservation are divided into three distinct Areas designated as the 100, 200, and 300 Areas. The majority of the reactor facilities are located in the 100 Areas. The reactor fuel processing and waste management activities are carried out in the 200 Areas. Research and development laboratories and fuel manufacturing facilities are located in the 300 Area (4-38).

Hanford - 100 Areas

Of the nine production reactors, which were utilized to produce plutonium-239, built in the 100 Areas between 1943 and 1959, only the dual-purpose reactor designated as "N" is still operating. This reactor is used to produce plutonium-239 as well as to supply steam for power generation. In addition to the reactor, 100 Area contains the Washington Public Power Supply System (WPPSS) generating plant, and 41 other buildings supporting the work at the reactor and generating station. Since 1966, the N reactor has been supplying low pressure stream to the WPPSS for electric power generation.

The radioiodines and tritium which are formed in the reactor coolant water are bled out of the loop into the ventilation exhaust air. The neutron activated argon-41 is also vented to the reactor exhaust air. All ventilation air is passed through HEPA filters and charcoal adsorbers before discharge out of the 200 foot stack. The ventilation flow rate at the N reactor is 150,000 cfm. Activated salts which form on the outside of reactor piping and entrained in air currents are removed by HEPA filtration.

The airborne effluents for 1972 included 10,000 Ci of ^{41}Ar, 27 Ci of tritium, 0.013 Ci of ^{131}I, 0.05 Ci of ^{133}I, less than 4.5 uCi of ^{90}Sr, and less than 0.37 uCi of ^{234}Pu.

Hanford - 200 Areas

The principal facilities of interest include the Purex Plant, the B Plant, and the Critical Mass Laboratory. The Purex Plant is an irradiated fuel processing plant utilizing the PUREX recovery process for plutonium, uranium and neptunium. The B Plant currently serves as a liquid waste treatment facility which strips ^{137}Cs and ^{90}Sr from Purex acid waste, high-level supernates, and sludges. The B Plant also has an encapsulation and storage facility attached to the plant. At the Critical Mass Laboratory, research on plutonium criticality safety is performed. High level liquid waste from the Purex Plant is stored in underground tanks.

Air flow is controlled through pressure zonation at all facilities. At the processing plants air is drawn into the plant through a washer and filter and is directed into the processing areas. After passing through the zone of highest contamination the air is passed through an exhaust duct containing HEPA filters before exiting the stack. All gaseous streams in the 200 Area facilities are treated either for particulate or radioactive gas removal before venting to the atmosphere. In general, multiple HEPA filtration is employed for particulate removal while silver reactors (silver zeolite molecular sieves) are employed for radioiodine removal. At the Purex Plant, two-stage glass fiber and HEPA filters are employed.

The system efficiency is given as 99.99% particulate removal for particles greater than 0.3 um at the Purex Plant. Over $3,900,000 have been expended recently for gaseous waste treatment improvements. The airborne radioactive effluents for 1972 included 0.21 Ci of ^{131}I, 0.81 Ci of gross-beta, 0.091 mCi of gross-alpha (assumed U), and 5.2 mCi of gross-alpha (assumed Pu).

Hanford - 300 Areas

The majority of the facilities in the 300 Area are dedicated to fuel fabrication (see Section 3 on nuclear fuel cycle facilities). The air cleaning systems at all facilities in this area, except Building 333, employ HEPA filtration. The wet uranium fume gaseous stream from the abrasive seals in Building 333 is passed through a wet scrubber. The HEPA filter system efficiency is annually tested in-place at 99.97% particulate removal for particles greater than 0.3 um by DOP smoke. The effluents for 1972 were about 0.042 Ci of ^{131}I, about 3.4 mCi of gross beta, and about 0.066 mCi of gross-alpha.

Brookhaven National Laboratory (BNL), N.Y.

The Brookhaven National Laboratory is a research facility operated under contract between the U.S. DOE and Associated Universities Incorporated and was founded in 1947 to create research capabilities to supplement the existing capabilities of the local academic institutions. The original research emphasis at Brookhaven was on nuclear science. However, environmental and energy development have been important areas of concentration in the past decade. The laboratory is located on a 5265 acre site in Suffolk County, New York about 60 miles due east of New York City.

Facilities at BNL include the High Flux Beam Reactor, a medical research reactor, several accelerators (see page 4-24), and numerous chemistry, physics, biology, and applied science laboratories. Several of these facilities and their associated airborne emission control technologies are reviewed below. Data on capital costs for installation of the control tecnnologies and annual operating costs could not be obtained. A discussion of capital costs for HEPA filter systems is provided in Appendix IIA. System specific efficiencies, annual residuals and airborne effluents of the facilities are given where available.

The High Flux Beam Reactor is a heavy-water 40 MW research reactor which provides intense neutron beams for neutron-matter studies. The core is a fully enriched uranium-aluminum alloy. The reactor building ventilation has a throughput rate of 20,000 cfm. All reactor building air is filtered through HEPA and charcoal adsorber filters before stack (320 foot) discharge. The reactor cover gas, composed primarily of helium, is passed through a charcoal filter before entering the exhaust gas system. Monthly system effluents are estimated to include 0.283 Ci of noble gases, 0.02 Ci of radioiodines, 0.11 mCi of argon-41, and 2.8 mCi of carbon-14.

The Medical Research Reactor is a SMW tank-type reactor utilizing 12 wt% enriched uranium-alluminum alloy fuel elements. The reactor is used in medical and biological research. The air cooling stream is passed through a series of HEPA filters prior to stack (150 foot) discharge. The principal radioactive gas discharged during routine operations is ^{41}Ar produced in the cooling air in the reactor's graphite reflectors. Argon-41 releases have been determined to be about 3 Ci/hr during operations, and have averaged about 500 Ci/year during the past several years.

Some 482 laboratory hoods are located in individual chemical laboratories within 29 different buildings. Hoods in which toxic materials or millicurie quantities of radioactive materials are handled, are equipped with HEPA filters and/or scrubbers for control.

The Hot Laboratory includes five semi-hot cells, three chemical processing hot cells, and three high-level hot cells for handling mullicurie amounts of radioactive materials in liquid, solid or gaseous form. Air flow is controlled through pressure zonation. Each cell is equipped with an individual HEPA filter as well as one backup filter. Exhaust air subsequent to filtration is vented through the High Flux Beam Reactor stack. Several process hot cells utilized for the recovery of radioiodines by dissolution of irradiated uranium samples have a separate air cleaning system. This system includes a sodium hydroxide scrubber with a backup charcoal filter. The total gross-beta activity currently released as radioparticulates from the laboratory is about 100 uCi/year.

Battelle Columbus Laboratories - Columbus, Ohio

Battelle Columbus Laboratories operates two facilities: the King Avenue site is involved predominantly with nuclear metallurgy, and the Nuclear Services Area near West Jefferson is involved in activities on irradiated fuel element studies and $^{235}U/^{239}Pu$ nitrate fuel studies.

At the Nuclear Services Area, air flow is controlled through pressure zonation. All exhaust streams containing potentially contaminated particulates are passed through HEPA filters first at the points of discharge from high contamination areas (e.g., glove boxes, test cells and hoods) and then near the stack through one or two banks of HEPA filters. Radioiodines from hot cell operations are passed through charcoal adsorber beds (4-39).

The system effluents for the West Jefferson site for calendar year 1976 included 2.77 mCi of krypton-85, 0.63 uCi of plutonium-239, 0.022 uCi of iodine-131, and 0.10 uCi of ruthenium-106.

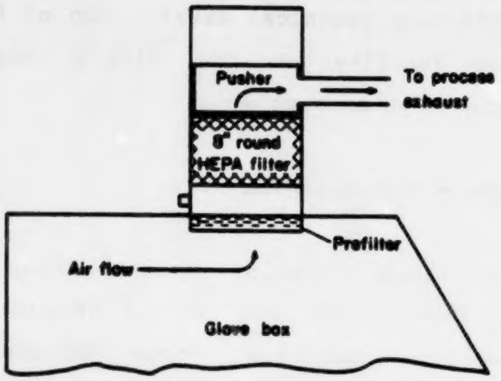
Los Alamos Scientific Laboratory (LASL), New Mexico

Los Alamos Scientific Laboratory site consists of approximately 28,000 arces of property in and adjacent to Los Alamos County, New Mexico. The laboratory has been operating since 1943. The work at LASL includes design and development of nuclear weapons, research programs in nuclear physics, chemistry, biology, biomedicine, radiochemistry, conventional explosives, metallurgy, hydrodynamics, hydrogeology, inertial confinement systems for fusion energy, space physics, laser and geothermal power research. Activities are carried out in 29 different technical areas. Two of the facilities at LASL, the Plutonium Facility and the Critical Experiment Facility, are examined below (4-40 through 4-42).

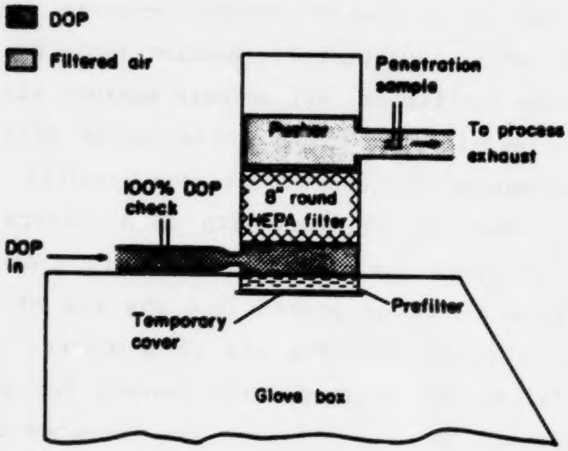
LASL - Plutonium Facility

The Los Alamos Plutonium Facility began operation in 1943 for preparation, fabrication, and recycle of plutonium metal and alloys for atomic weapons production. Since 1953 the plutonium facility has been used for various research and development activities relating to plutonium and its alloys. One part of the facility was created in 1945-1946 and was utilized extensively into the 1970's; another part of the facility was constructed in mid 1970's, contains more advanced air cleaning technologies, and is examined below.

Air flow is controlled through pressure zonation. Pursuant to the AECM Appendix 6301-Part II, Section H-Minimum Design Criteria for New Plutonium Facilities, all process exhaust air from glove boxes is designed to permit easy in-place testing of HEPA filters and to confine contamination to the smallest zone possible. The exhaust ducting from glove boxes is equipped with HEPA filters in a position very close to the glove box wall (Figure 4.8a). An eight inch (203 mm) circular HEPA filter is pushed into the top of the cylindrical holder and into place with the aid of a pusher. Both the pusher and circular filter are equipped with gaskets for proper sealing within the cylindrical column. Filters are replaced by introducing a new filter and pusher at the holder top and pushing the spent filter into the glove box for disposal. The filter efficiency testing is accomplished in-place with a DOP smoke operator (see Figure 4.8b). The testing procedure consists of the following steps: (a) a temporary cover is placed over the prefilter in the glove box; (b) a temporary duct is introduced into the filter holder midway between


Pusher
To process exhaust
8" round HEPA filter
Prefilter
Air flow
Glove box

(A) GLOVE BOX FILTER INSTALLATIONS


DOP
Filtered air
Penetration sample
Pusher
To process exhaust
100% DOP check
8" round HEPA filter
DOP in
Prefilter
Temporary cover
Glove box

(B) GLOVE BOX FILTER INSTALLATION FILTER TEST

GLOVE BOX FILTER

SOURCE: REF. 4-41

DAMES & MOORE

FIGURE 4.8(A) & 4.8(B)

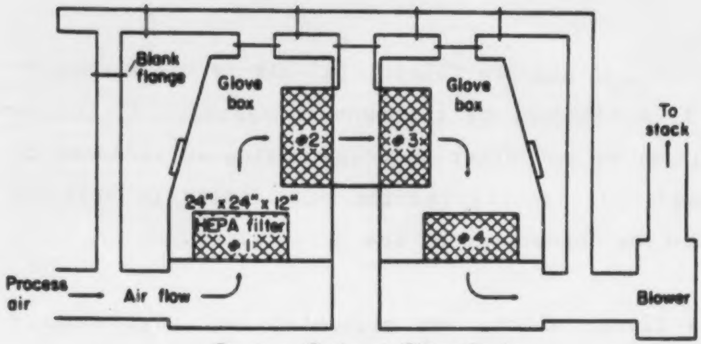
the HEPA filter and pre-filter; (c) air is drawn through the temporary duct and is filtered by the exhaust system; (d) the aerosol (DOP) is then introduced and after thorough mixing an influent concentration is determined; and finally (e) the penetration is measured at a convenient location downstream of the HEPA filter.

The layout of the new plutonium facility resulted in the construction of four separate process gaseous stream exhaust systems each less than 2000 cfm (0.95 m^3/s). The typical process exhaust filter system (Figure 4.9A) consists of two glove box enclosures connected back-to-back allowing for up to four stages of HEPA filtration. Each filter stage employs two 24"x24"x12" HEPA filters with sufficient space to add another filter in each stage. The process for in-place testing of each stage is illustrated in Figures 4.9B through 4.9E.

Room air at the new plutonium facility is recirculated at a rate of eight changes per hour with fresh air comprising approximately 10% of the volume. Recirculated air is passed through two stages of HEPA filters before discharge. The room circulation filter plenums and the room air bleed-off filter plenums are designed and sized at 20,000 cfm or less. Each compartment recirculation will have two plenums each handling 50% of the total compartment air flow. Bleed-off systems are equipped with two plenums each capable of handling 100% of the normal air flow. The typical recirculation or bleed-off plenum is illustrated in Figure 4.10A. During routine operation flanged openings at the top of the plenums and exhaust ducts are equipped with blind covers. For in-place DOP testing, temporary 24" ducts are connected to these flanged openings. The methods for testing specific stages in this system are illustrated in Figures 4.10B through 4.10E.

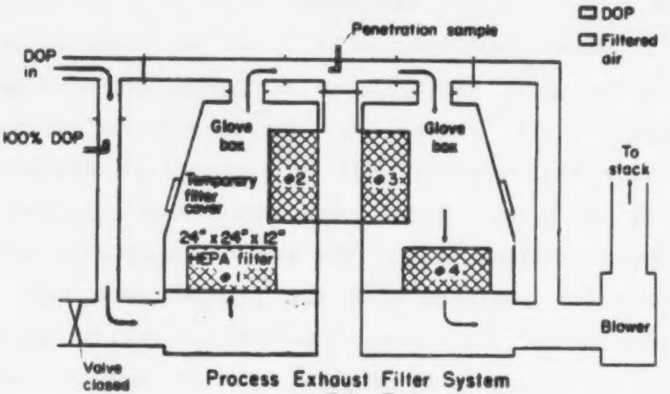
LASL - Critical Experiment Facility

The facility consists of three different buildings where critical assemblies are remotely operated from separate control buildings. The


Blank flange
Glove box
Glove box
#2
#3
To stack
24" x 24" x 12" HEPA filter #1
#4
Process air
Air flow
Blower

Process Exhaust Filter System

(A)


Penetration sample
DOP
Filtered air
DOP in
100% DOP
Glove box
Glove box
Temporary filter cover
#2
#3
To stack
24" x 24" x 12" HEPA filter #1
#4
Blower
Valve closed

Process Exhaust Filter System
1 Filter Test

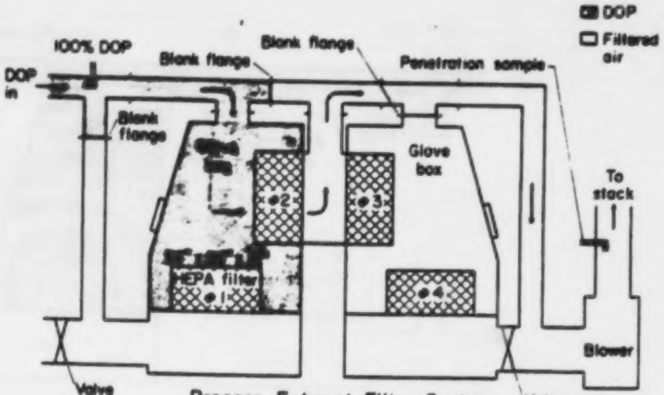
(B)

PROCESS EXHAUST FILTER SYSTEM

SOURCE: REF. 4-41

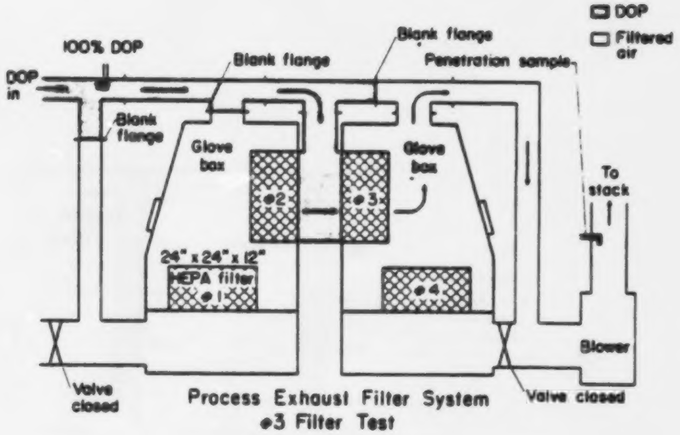
DAMES & MOORE

FIGURE 4.9(A) & 4.9(B)


DOP
Filtered air
100% DOP
DOP in
Blank flange
Blank flange
Blank flange
Penetration sample
Glove box
To stack
#2
#3
HEPA filter #1
#4
Blower
Valve closed
Valve closed

Process Exhaust Filter System
#2 Filter Test

(C)


DOP
Filtered air
100% DOP
DOP in
Blank flange
Blank flange
Blank flange
Penetration sample
Glove box
Glove box
To stack
#2
#3
24" x 24" x 12"
HEPA filter #1
#4
Blower
Valve closed
Valve closed

Process Exhaust Filter System
#3 Filter Test

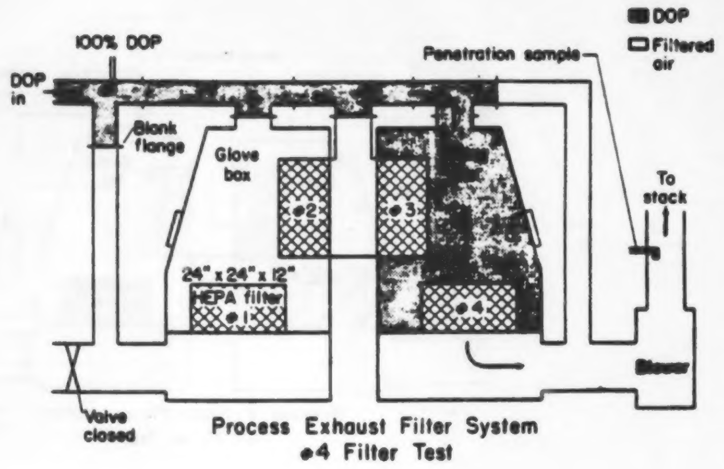
(D)

PROCESS EXHAUST FILTER SYSTEM

SOURCE: REF. 4-41

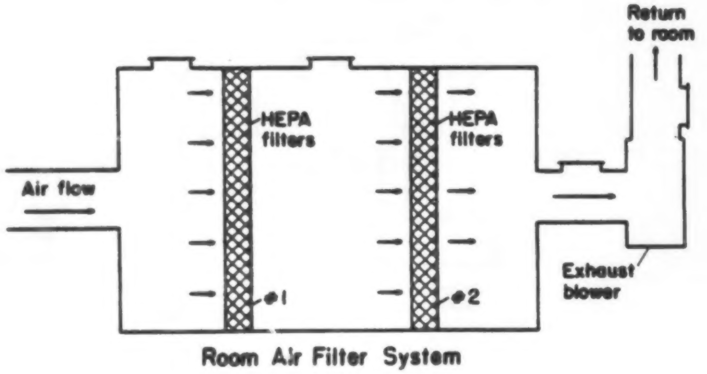
DAMES & MOORE

FIGURE 4.9(C) & 4.9(D)


100% DOP
DOP in
Blank flange
Glove box
#2
#3
Penetration sample
DOP
Filtered air
To stack
24" x 24" x 12" HEPA filter
#1
#4
Blower
Valve closed
Process Exhaust Filter System
#4 Filter Test

(E)

PROCESS EXHAUST FILTER SYSTEM

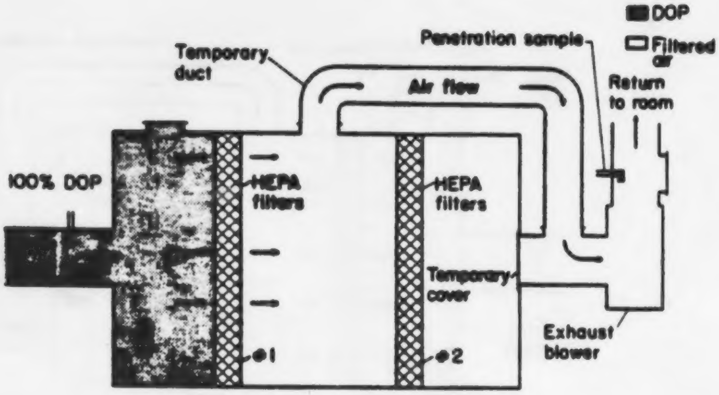

Return to room
HEPA filters
HEPA filters
Air flow
#1
#2
Exhaust blower
Room Air Filter System

(A)

ROOM AIR FILTER SYSTEM

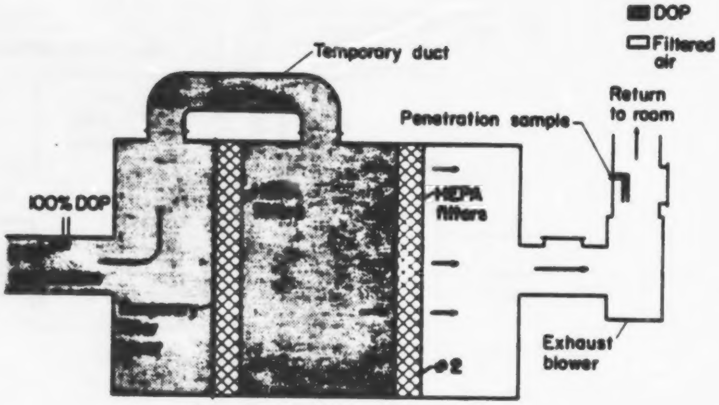
Source: Reference 4-41

DAMES & MOORE


DOP
Filtered air
Penetration sample
Temporary duct
Air flow
Return to room
100% DOP
HEPA filters
HEPA filters
Temporary cover
Exhaust blower
#1
#2

Room Air Filter System
Filter Bank #1 Test

(B)

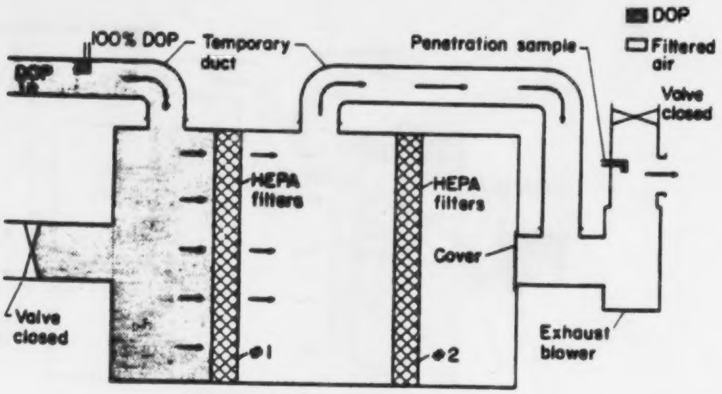

DOP
Filtered air
Temporary duct
Return to room
Penetration sample
100% DOP
HEPA filters
Exhaust blower
#2

Room Air Filter System
Filter Bank #2 Test

(C)

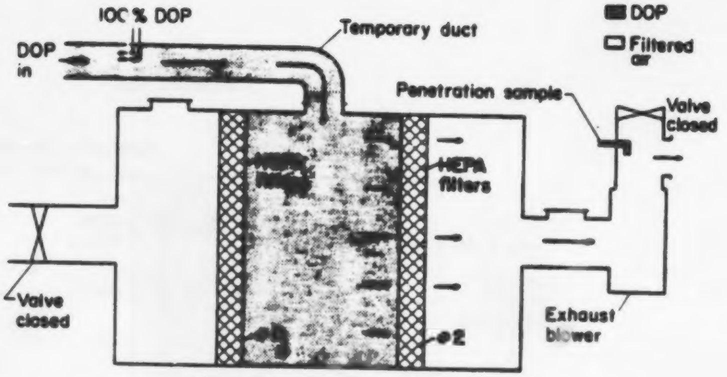
ROOM AIR FILTER SYSTEM

SOURCE: REF. 4-41


100% DOP
Temporary duct
Penetration sample
DOP
Filtered air
DOP in
Valve closed
HEPA filters
HEPA filters
Cover
Valve closed
Exhaust blower
#1
#2

Room Air Filter System
Filter Bank #1 Test

(D)


100% DOP
Temporary duct
DOP
Filtered air
DOP in
Penetration sample
Valve closed
HEPA filters
HEPA filters
Valve closed
Exhaust blower
#2

Room Air Filter System
Filter Bank #2 Test

(E)

ROOM AIRFILTER SYSTEM

Source: Reference 4-41

DAMES & MOORE

FIGURE 4.10(D) & 4.10(E)

critical assembly facilities are operated to provide design information for experimental nuclear explosive devices, safe handling, storing, and transporting of weapons and to provide neutron data for weapon systems calculations.

The only isolation and infiltration system is that associated with the Kinglet solution tank which is a liquid critical assembly device. The tank provides confinement (hold-up) of radioactive gases until conditions are appropriate for release through a HEPA filter and charcoal trap.

REFERENCES

II.4-1 U.S. Nuclear Regulatory Commission. Code of Federal Regulations. Title 10, 1978.

II.4-2 U.S. Nuclear Regulatory Commission. Facilities Licence Application Record. May 31, 1978.

II.4-3 Union Carbide Corporation. Tuxedo, New York. Personal communication*, 1979.

II.4-4 University of California at Irvine. Personal communication*, 1979.

II.4-5 Michigan State University. East Lansing, Michigan. Personal communication*, 1979.

II.4-6 Columbia University. New York, New York. Personal communication*, 1979.

II.4-7 Massachusetts Institute of Technology. Cambridge, Massachusetts, Personal communication*, 1979.

II.4-8 North Carolina State University. Raleigh, North Carolina. Personal communication*, (1979).

II.4-9 U.S. National Bureau of Standards. Preliminary Hazards Summary Report Bureau of Standards Research Reactor. Gaithersburg, Maryland, Docket 80-184, 1978.

II.4-10 U.S. National Bureau of Standards. Gaithersburg, Maryland. Personal communication*, 1979.

* Individual chose to remain anonymous.

REFERENCES

II.4-1 U.S. Nuclear Regulatory Commission. Code of Federal Regulations. Title 10, 1978.

II.4-2 U.S. Nuclear Regulatory Commission. Facilities Licence Application Record. May 31, 1978.

II.4-3 Union Carbide Corporation. Tuxedo, New York. Personal communication*, 1979.

II.4-4 University of California at Irvine. Personal communication*, 1979.

II.4-5 Michigan State University. East Lansing, Michigan. Personal communication*, 1979.

II.4-6 Columbia University. New York, New York. Personal communication*, 1979.

II.4-7 Massachusetts Institute of Technology. Cambridge, Massachusetts, Personal communication*, 1979.

II.4-8 North Carolina State University. Raleigh, North Carolina. Personal communication*, (1979).

II.4-9 U.S. National Bureau of Standards. Preliminary Hazards Summary Report Bureau of Standards Research Reactor. Gaithersburg, Maryland, Docket 80-184, 1978.

II.4-10 U.S. National Bureau of Standards. Gaithersburg, Maryland. Personal communication*, 1979.

* Individual chose to remain anonymous.

REFERENCES (cont'd)

II.4-11 Williams, L.D. Plutonium Recycle Critical Facility Final Safety Analysis Report. Battelle Memorial Institute, Pacific Northwest, Pacific Northwest Laboratory, Docket 50-310, April, 1970.

II.4-12 Alexander, R.E. (ed.). Radiation Safety of Atomic International. Atomic International (A dvision of North America Aviation, Inc.), Docket 70-1047, March 1, 1967.

II.4-13 Knapp, P.A. Application for Renewal of Special Nuclear Material License. Isotopes (A Teledyne Co.) Westwood Laboratories, SNM-107, Docket 70-124, November 18, 1968.

II.4-14 Union Carbide Corporation. Application for Special Nuclear Material License Amendment. Docket 70-687, 1976.

II.4-15 Union Carbide Corporation. Hazards Report for Radioactive Materials Laboratory. Docket 70-687, June 15, 1962.

II.4-16 National Aeronautics & Space Administration. Langley Research Center. Application for Extension of Authorized Use Under License Number SNM-1288. 1976.

II.4-17 Van Loocke, F.G., & Schaeffer, M.R. Application for Special Nuclear Materials License. Reactive Metals, Inc. Docket 70-977, October 1966.

II.4-18 Todd Shipyards, Corp. Research & Technical Division. Application for Special Nuclear Material License Amendment. Docket 070-01062, February 13, 1976.

II.4-19 African Metals Corp. Application for Source Material License. July 15, 1974.

REFERENCES (cont'd)

II.4-20 Bell Telephone Laboratories, Inc. Application for Source Material License. 1975.

II.4-21 Chicago Magnesium Casting Co. Application for Source Material License. July 18, 1972.

II.4-22 Minnesota Mining and Manufacturing Co. Application for Source Material License. April 4,1974.

II.4-23 Molycorp, Inc. Application for Source Material License. December 26, 1974.

II.4-24 Westinghouse Electric Corp. Research & Development Center. Pittsburgh, PA. Application for Source Material License. Pittsburgh, Pa: November 1, 1973.

II.4-25 Wright Patterson Air Force Base. Application for Source Material License. July 18, 1972.

II.4-26 U.S. Energy Research & Development Administration. Final Environmental Impact Statement: Brookhaven National Laboratory - Upton, New York. ERDA-1540, 1977.

II.4-27 Baker, S.I. Fermi National Accelerator Laboratory: Environmental Monitoring Report for Calendar Year 1976. Environmental Monitoring of Major U.S. Energy Research & Development Administration Contractor Sites. 1977.

II.4-28 U.S. Energy Research & Development Administration. Final Environmental Impact Statment: Positron-Electron Storage Ring Project-Stanford Linear Accelerator Center, Stanford, California. ERDA-1546, 1976.

REFERENCES (cont'd)

II.4-29 U.S. Department of Energy. *Final Environmental Impact Statement: Proton-Proton Storage Accelerator Facility (Isabelle), Brookhaven National Laboratory, Upton, New York.* DOE/EIS-0003, 1978.

II.4-30 Kulcinski, G.L., *et al.* "Energy for the Long Run: Fission or Fusion." *American Scientist*, Vol. 67, 1979.

II.4-31 U.S. Department of Energy. *Preliminary Safety Analysis Report - Princeton Plasma Physics Laboratory Tokamak Fusion Test Reactor.* 1977.

II.4-32 Easterly, C.E., Shank, K.E. and Shoup, R.L. "Radiological and Environmental Aspects of Fusion Power." *Nuclear Safety*, Vol. No. 182, 1977.

II.4-33 Farmer, B.M., Robinson, R. and Carfagno, D.G. *Annual Environmental Monitoring Report: Calendar Year 1976, MLM-2416, part of Environmental Monitoring at Major U.S. Energy Research & Development Administration Contractor Sites.* U.S. Energy Research & Development Administration, ERDA 77-104, 1977.

II.4-34 Alexander, R.E. *Environmental Monitoring Report for Pantex Plant Covering 1976, part of Environmental Monitoring at Major U.S. Energy Research & Development Administration Contractor Sites.* U.S. Energy Research & Development Agency, ERDA 77-104, 1977.

II.4-35 General Electric Company. *Environmental Monitoring Report 1976: Pinellas Plant St. Petersburg, Florida, part of Environmental Monitoring at Major U.S. Energy Research & Development Administration Contractor Sites.* U.S. Energy Research & Development Agency, ERDA 77-104, 1977.

REFERENCES (cont'd)

II.4-36 Hornbacher, D.D. *Annual Environmental Monitoring Report, U.S. Energy Research & Development Administration, Rocky Flats Plant, part of Environmental Monitoring at Major U.S. Energy Research & Development Administration Contractor Sites.* U.S. Energy, Research & Development Agency, ERDA 77-104, 1977.

II.4-37 U.S. Energy Research & Development Administration. *Final Environmental Impact: Waste Management Operations, Idaho National Engineering Laboratory.* ERDA-1536, 1977.

II.4-38 U.S. Energy Research & Development Administration. *Final Environmental Statement: Waste Management Operations, Hanford Reservation, Richland, Washington.* ERDA-1538, 1975.

II.4-39 Battelle Columbus Laboratories. *Environmental Report for Calender Year 1976, part of Environmental Monitoring at Major U.S. Energy Research & Development Administration Contractor Sites.* U.S. Energy Research & Development Agency, ERDA 77-104, 1977.

II.4-40 U.S. Atomic Energy Commission. *Environmental Statement: Plutonium Facility, Los Alamos Scientific Laboratory, New Mexico.* WASH-1506, 1972.

II.4-41 Mitchell, R., *et al.* *Design of Ventilation and Air Cleaning Systems for the New Los Alamos Plutonium Facility.* LA-UR-74-1051, 1974.

II.4-42 Paxton, H.C. *Safety Analysis of the Los Alamos Critical Experiments Facility, Los Alamos Scientific Lab, New Mexico.* LA-6206, 1976.

CHAPTER II

Section 5: Fossil Fuels

Introduction

Purpose of Study

The objective of this section of the study is to evaluate the control technologies that limit the emission of radioactive airborne particulates in electric generating plants utilizing fossil fuels. This section will deal only with existing technologies; later sections will deal with advanced technologies.

After an extensive review of the literature and conversations with people in the field, it was concluded that scant data exists relating to the direct control of radionuclide emissions in fossil fuel burning electric generating plants. Consequently, the approach to the problem of reducing the emission of radioactive airborne particulates has been through the examination of control technologies that limit emission of airborne particulates in general.

There is evidence that, with the exception of radon gas, a significant fraction of radioactive particles are captured by the control devices that likewise capture other non-radioactive combustion residuals. The literature indicates that activity concentration is higher in the fine particulates (5 microns and smaller) than in larger particulates. The objective of this section is to identify the kinds of control technologies that have the capability of capturing the greatest percentage of airborne particulates escaping in the stack gas, and thus, capturing a greater portion of the fine fraction on which the radionuclides would be concentrated.

Organization

This section includes the following sub-sections:

- Particulate emissions that arise from the storage, transport and surface mining of coal. Each activity has particulate emission points which are discussed.

- Radionuclides found in coal are examined. Combustion of coal releases radionuclides that have been geologically deposited in the coal. There is evidence that the nature of the geological deposition determines the behavior of the radionuclides during combustion. The amounts and characteristics of radionuclides in coals from various regions of the county will be examined.

- Radionuclides and control devices or natural gas and fuel oil are addressed. Emissions from coal fired plants are given greater consideration than from natural gas or fuel oil fired plants because coal fuel plants generally emit more particulates.

- Particulate control device evaluation includes a brief review of the three major particulate control devices - electrostatic precipitators, fabric filters, and scrubbers. Each control device is evaluated using the four criteria of efficiency, costs, energy use and residuals. Each of these criteria is defined in Chapter 1.

Last a survey of 21 fossil-fueled power plants is presented. In an attempt to determine the exemplary control technologies in existence on fossil-fueled power plants, a survey was taken of 153 plants meeting New Source Performance Standards (NSPS).(5-1) The National Emissions Data System (NEDS) was utilized to identify fossil-fuel burning electric generating plants that are meeting NSPS. These plants are currently meeting the regulations for the highest air quality standards for fossil-fueled plants. Twenty one of these plants were chosen for analysis as geographically representative samples from the 153 plants listed as meeting the NSPS.

Standards

Emission standards for fossil fuel fired electric generating plants are established by the EPA. Present standards for particulate matter emissions are that "no owner or operator shall cause to be discharged into the atmosphere from any affected facility any gases which: contain particulate matter in excess of 43 ng/J heat input (0.10 lb/million Btu) derived from fossil fuel and wood residue."(5-2)

The proposed standards for particulate matter emissions

> "....would limit the emissions of particulate matter to 13 ng/J (0.03 lb/million Btu) heat input and would require a 99-percent reduction in uncontrolled emissions from solid fuels and a 70-percent reduction for liquid fuels. No particulate matter control would be necessary for units firing gaseous fuels alone, and thus a percent reduction would not be required.
>
> The proposed standards are based on the performance of a well designed and operated baghouse or electrostatic precipitator (ESP). EPA has determined that these control systems are the best adequate demonstrated systems of continuous emission reduction (taking into consideration the cost of achieving such emission reduction,

and any non-air quality health and environmental impact, and energy requirements)."(5-2)

Note that this section of this study is concerned primarily with existing regulations.

Data Acquisition

The primary sources of information used in the preparation of this section of the report were:

- Published scientific and technical literature, both primary journals and abstracts.

- Government reports from the Bureau of Mines, Environmental Protection Agency, Department of Energy, National Science Foundation, Tennessee Valley Authority, U.S. Geological Survey, Oak Ridge National Laboratory, and Electric Power Research Institute and others.

- Telephone and personal contacts with individuals in government agencies, consultants, Dames & Moore staff members, and staff members at institutes conducting research on the subjects of our interest.

Coal Extraction, Transport and Storage

This part of the report addresses particulate emissions from the coal surface mining industry. Underground mining will not be included since our concern is the evaluation of control technologies for the reduction of radioactive emissions into the ambient atmosphere. An area of study identified for continuing research is that of radioactive emissions from deep mines, but neither radioactive particulates nor gaseous emissions from deep mines will be considered here.

Industry Description

Resources and Reserves

The Bureau of Mines defines four basic terms for the classification of mineral resources:(5-3)

> Resource - A concentration of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust in such form that economic extraction of a commodity is currently or potentially feasible.
>
> Identified resources - Specific bodies of mineral-bearing material whose location, quality, and quantity are known from geologic evidence supported by engineering measurements with respect to the demonstrated category.
>
> Undiscovered resources - Unspecified bodies of mineral-bearing material surmised to exist on the basis of broad geologic knowledge and theory.
>
> Reserve - That portion of the identified resource from

which a usable mineral and energy commodity can be economically and legally extracted at the time of determination. The term ore is used for reserves of some minerals.

The U.S. Geological Survey estimates that there are 3.9 trillion tons of coal resources in the U.S. Of this total resource, 1.7 trillion tons are identified resources and 2.2 trillion are hypothetical resources (see Table 5-1).

Hypothetical resources are that portion of the undiscovered resources postulated to exist in known coal bearing districts. Speculative resources, postulated to exist in undiscovered districts, are not included in the totals presented here. Resource estimates currently include coal deposits in beds of minimum thicknesses of 14 inches or more for bituminous coal, 30 inches or more for sub-bituminous coal, and lignite at depths up to 6000 feet.

According to the Bureau of Mines, about 429 billion tons of the identified resources are classified as demonstrated reserves. Demonstrated reserves are that portion of the reserve base related to coal deposits at depths and seam thicknesses similar to those from which coal is currently being mined. (i.e., seam thickness of 28 inches or more for bituminous coal and 60 inches or more for sub-bituminous coal and lignite, at depths up to 250 feet for surface mining and 1000 feet for underground mining). These reserves contain approximately 5000 quadrillion BTUS (Quads) of heat energy. For comparison, one quad is equivalent to the energy contained in 180 million barrels of oil or one trillion cubic feet of natural gas.

Coal represents about 90 percent of the nation's fossil fuel reserves. Current reserves are sufficient to satisfy the U.S. demand for about 100 years, based on a high demand forecast that assumes a 3.69 percent annual growth rate to the year 2000 and a constant demand thereafter.

TABLE 5-1

U.S. Coal Resources and Reserves (Millions of Tons)[a]

Region	Resources[b]			Demonstrated Reserve Base[c]
	Identified	Hypothetical	Total	
Eastern	259,935	93,685	353,620	97,690
Central	220,035	128,152	348,187	97,364
Western	1,234,287	1,975,287	3,209,795	234,287
Total	1,714,257	2,197,345	3,911,602	429,341

---

[a] Resources and reserve estimates exclude anthracite coal deposits.

[b] Resource estimates as of January 1, 1974 (U.S. Geological Survey).

[c] March 1975 estimates (Bureau of Mines).

Ref: 5-4

Location of U.S. Coal

Most of the coal resources in the U.S. (54%) are found west of the Mississippi River, where approximately 82 percent of the demonstrated reserve base is located. These percentages equal about 3.2 trillion tons of coal resources and 232 billion tons of demonstrated reserves.

Production of Coal

In 1976, underground mining produced 296 (45%) million tons of coal while surface mining produced 369 (55%) million tons of coal, totaling 665 million tons. The techniques of surface mining are substantially more productive than those of underground mining. In 1976, underground mining productivity was 8.50 tons per worker-day. For surface mining (both strip and auger) it was 26.00 tons per worker-day. Raised productivity in surface mining has come about through the development of large capital intensive equipment such as draglines, haulers, drillers, front-end loaders, etc. Table 5-2 highlights the changes in mining productivity that have occurred during the past 36 years.

Future Demand

Coal demand estimates vary widely. The Edison Electric Institute (EEI) scenario calls for 779 million tons by 1985; the Bureau of Mines (BOM) says 988 million tons; and the National Energy Plan calls for 1.2 billion tons. The EEI and BOM scenarios are presented in Table 5-3. Production figures are broken into regional totals by mining method and are compared to actual production figures for 1974.

TABLE 5-2

Coal Industry - Productivity and Mining Trends[f]

	Worker Productivity[a]			Mine Production[b]		
Year	Underground	Surface[c]		Underground	Surface	Total
		Strip	Auger			
1940	4.86	15.63		418 (91)	43 (9)	461
1945	5.04	15.46		468 (81)	110 (19)	578
1950	5.75	15.66		393 (76)	123 (24)	516
1955	8.28	21.12	22.22	344 (74)	121 (26)	465
1960	10.64	22.93	31.36	285 (69)	131 (31)	416
1965	14.00	31.98	45.85	333 (65)	179 (35)	512
1970	13.76	35.96	34.26	339 (56)	264 (44)	603
1973	11.66	36.30	45.33	299 (51)	292 (49)	591
1975	9.54	d/26.69		292 (45)	356 (55)	648
e/1976	8.50	d/26.00		296 (45)	369 (55)	665

---

a. Units are in tons of coal produced per worker - day.

b. Given in millions of tons of coal. Numbers in parentheses are percents (of totals) mined by that method.

c. Strip and auger mining are described in the glossary.

d. Strip and auger mining combined.

e. All 1976 figures are estimates.

f. Ref. 5-4.

Table 5-3

Future Coal Production Scenarios (Millions of Tons)*

	1974 (actual)	1985		2000	
		EEI	BOM	EEI	BOM
Eastern	377.7	337.6	428.0	407.9	687.6
Underground	212.3	211.1	295.4	281.6	474.7
Surface	165.4	126.5	132.6	126.3	212.9
Central	142.5	147.8	161.4	153.6	257.5
Underground	54.8	64.8	72.6	69.2	116.1
Surface	87.7	83.0	88.8	84.4	141.4
Western	83.2	293.8	398.6	380.5	641.3
Underground	10.2	26.5	41.7	39.8	67.0
Surface	73.0	267.9	356.9	340.7	574.3
Total U.S.	603.4	779.2	988.0	941.9	1,586.4
Underground	326.1	302.4	409.7	390.5	657 8
Surface	277.3	476.8	578.3	551.4	928.6
New Mines opening (1975 to 1985)	-	152	254	-	-
New Mines opening (1976 to 2000)	-	-	-	286	571

---

* Ref. 5-4. Figures represent Edison Electric Institute (EEI) and Bureau of Mines (BOM) scenarios.

Geology

Geological Formation of Coal

Coal is a combustible sedimentary rock formed by partial to complete decomposition of buried vegetation that is then compacted and subjected to elevated pressures and temperatures. Coals are characterized by their rank, nature of the plant remains, and depositional conditions. The variations in rank are of greatest importance for industrial purposes. Increasing metamorphism results in important changes in coal properties. Lignite coal has a low heating value, 30-40% water content, and a high ash content. Bituminous coal has fixed carbon and volatile matter in about equal amounts, and makes excellent coke. Anthracite coal, known as hard coal, has a high fuel efficiency, and is the least abundant in the U.S. In a gradient from lignites to anthracite coals, the lignites have been subjected to the least metamorphism, while anthracite coals have been subjected to the most (hence the dense carbonaceous quality of anthracite).

Radionuclides in Coal

The kinds and amounts of radionuclides found in coal and its combustion products are discussed later in this section.

Particulate Emissions and Controls

Surface Mining

Surface mining is a major method of mining coal in the U.S. Over one half of the coal produced in this country is mined by open pit or auger mining. Approximately one-half of this coal is produced in Kentucky, Ohio and Illinois.

Surface coal mining refers to strip and auger mining of coal that lies near the surface of the earth. It is practiced extensively in all of the coal bearing areas of the United States. The open pit mining process is a source of particulate air pollution.

Open pit coal mining consists of several unit operations such as drilling, blasting, excavation of overburden, removal of the coal, and coal transport. Each unit operation contributes to the total dust emissions produced by the suface mining of coal. Table 5-4 presents the contribution of respirable particulate emissions to the national open coal mining rate from the various unit operations and windblown sources within surface mines. It can be seen that blasting, coal transport, and coal loading and unloading account for 85% of the respirable particulate emissions. Wind erosion, overburden stripping, coal augering and reclamation activities combined contribute only four percent to the national total.

The respirable dust emissions presented in Table 5-4 were obtained from an EPA study, Open Mining of Coal - State of the Art. (5-5) The EPA concluded that the respirable particulate emissions (less than 7 um) from the surface coal mining industry in 1972 totalled about 3,600 metric tons. Emission rates were based on assumed emission factors. The emission factors for the unit operations indicated that 13g of respirable dust is emitted per metric ton of coal mined. Approximately 0.019g of respirable dust emissions occur via wind erosion of the mined surface per second per square kilometer of mined land.

Almost no control technologies are used to limit particulate emissions at surface mines. The exceptions are as follows:

1. Dust control during drilling of blast holes can be accomplished by using a variety of cyclones and baghouses to capture emissions.

TABLE 5-4

Contribution to Respirable Mining Dust
Emissions From Each Source Within the Mine
(percent of national mining total)

Source	Coal Dust	Overburden Dust	Total Dust
Wind erosion	1.6	1.6	3
Drilling	5.8	5.8	12
Overburden stripping	0	0	0
Coal loading	14	0	14
Coal transport and unloading	40	0	40
Blasting	30	0	30
Coal augering	1	0	1
Reclamation	0	0	0
National Total	93	7	100

Ref. 5-5

2. When rubber tired equipment hauls coal, it creates more dust than do crawler units. Applying asphalt to roads suppresses the dust. Most states require water spraying of haul roads to reduce dust emissions.

Some possible or experimental control technologies include:

1. Extensive use of a wetting agent, a surfactant or chemical spray to be applied to roads and to ore during handling operations. They are more effective than plain water.

2. Loading and unloading coal generates dust. Using enclosures or covers during the process may limit some emissions.

3. Curtailment of wind entrainment from mine roads by using either water or an emulsified asphalt.

4. Construction of windbreaks, fencing, planting of ground cover and protection by other vegetation in the area can shield areas from wind entrainment.

Transport of Coal

Coal is extracted from surface or underground mines and then transported to a point where it will be used as fuel in a combustion process. It is possible that by 1985, over one billion tons will be transported each year to some destination. The mode of transportation is often dictated by physical conditions such as terrain, climate, water resources, navigability of waterways, and distance. Railroads carry most of the coal that is transported over 100 miles; barges carry the second largest quantities over long distances. Trucks are the major haulers over short distances because of their versatility. Slurry pipelines and conveyor belts are used to a lesser extent.

A. Train Transport

The EPA used the following model to determine airborne emissions from a unit train transporting coal.

> "a 126-car train supplying 11,430 metric tons (12,600 tons) per trip. The unit train is loaded at the mine site onto nine 2240-kw (3000-hp) diesel locomotives for transport to the power plant 490 km (306 miles) away. The locomotives are of the two-stroke supercharged road variety. Upon arrival at the power plant the coal is unloaded from the cars through bottom grates. The total time for the haul from the mine and back is 48 hours. Emissions resulting from the 985-km (612-mile) round trip are summarized in Table 5-5".(5-6)

Estimates of emissions during unloading are based on the EPA's emission factor of 0.2 kg/metric ton. Estimates for discharge of particulates in loading are assumed to be the same as in unloading.

During transport there is a loss of coal dust/particulates. The loss depends upon the moisture and fines content of the coal, the speed of the train and the wind speed. Estimates vary, but probably about 0.05 to 1.0 percent of the total coal is lost during a 300 mile trip. Several methods can be used to reduce the particulate emissions on long trips. Wind guards can be used on the cars to deflect high winds caused by the weather or to protect the coal against the loss caused by the air rushing over a speeding train. Washed coal which retains some moisture reduces emissions. Sealing the surface layer with an asphalt emulsion or other sealant may be effective. Adding

TABLE 5-5

Coal Particulate Emissons From Unit Train on 985-KM (612 Mi.) Round Trip

Load: 11,430 metric tons (12,600 tons)

Source	Air Emissions kg(lb)/Trip
Loading	2,285 (5,040)
Unloading	2,285 (5,040)
Fugitive emissions, in transit (0.05%)	5,700 (12,600)

Ref. 5-6.

oil or calcium chloride to the coal proves effective. Tarpaulins physically placed on each car are a very good control method except for the fact that it is labor intensive. Flip-top lids for gondola cars are in limited use for preventing snow from settling in the cars, and as a side benefit, prevent dust loss and spillage.

B. Barge Transport

An average load for a typical barge carrying coal on an inland waterway might be about 18,000 metric tons. Barges are loaded at a site along the river where a towboat lashes a number of barges together.

Data for emissions for loading and unloading barges is estimated to be similar to that for rail cars (0.20 kg/metric ton or 0.04 lb/ton). On this basis, for an 18,100 metric ton barge shipment, which is a typical example, 3630 kg (8000 lb) of dust would escape during loading or unloading. The unloading stations usually include a clamshell to pick up coal from the barge. The coal is placed in a bin from where it is often placed on conveyors to be taken to a stockpile. Dust is released as the clamshell removes coal from the barge and drops it in the bin. High winds increase the problem substantially.

The receiving bin can be equipped with sprays on the feeder discharge points to control dust. Also, the sides can be extended to protect the coal from the wind. A negative pressure in the bin to provide a downward flow of air from the top will reduce dust emissions.

Emission losses from a loaded barge during transit are not measured and are therefore unknown. Some have estimated that the windage losses over a two day trip would be approximately 0.02 percent. Treating the coal on the barges in a manner similar to rail transported coal would probably reduce emissions during transit.

Table 5-6 gives emissions for barge transport of coal.

TABLE 5-6

Coal Particulate Emissions From Barge Transport of Coal

Load: 18,100 metric tons
(20,000 tons) of coal

Source	Air Emissions kg (lb)/Trip
Loading	3630 kg (8,000 lb)
Unloading	3630 kg (8,000 lb)
Fugitive emissions in transit (0.01%)	1800 (4000)/day

Ref. 5-6.

C. Conveyor Belt Transport

Conveyor belts carry coal from one point to another, usually from a dump site to the site where the coal will be utilized. Spillage and fugitive dust are associated with the transfer and discharge points as well as enroute on the belt. An example of a conveyor operation is at Gallipolis, Ohio, where a belt transports 29,000 metric tons of coal on a typical day from a mine to a plant. If wind losses are assumed to be 0.02 percent, and 0.075 kg/metric ton (0.15 lb/ton) lost from controlled spillage at transfer stations, the amount of coal lost per day would be 5760 kg (12,800 lb) by windage and 6350 kg (14,400 lb) from all transfer points combined.(5-6)

Transfer stations are usually enclosed in order to minimize the discharge of particulates to the air. Hoods or vents on dust collectors capture some emissions at the transfer points.

D. Truck Transport

Trucks transport coal from mines to a site where the coal is burned, stored or transferred to another mode of conveyance. As a model, a diesel powered uncovered truck with a 27 metric ton (30 ton) payload with 20 miles to go on a one way haul, would average 0.05 percent of the total coal payload lost. Losses in loading and unloading were assumed to be 0.04 percent. Table 5-7 summarizes air emissions from truck transport of coal.

Other than watering down access roads to the mines, little if anything is done to suppress dust within the mine area. Wind loss and spillage will occur during transport unless the top of the truck is covered. If the moisture content of the coal is 3 percent or greater, dust emission is curtailed to some degree. Organic sealants would reduce wind losses from the transport of coal, but would not prevent the spillage.

TABLE 5-7

Coal Particulate Emissions From Truck Transport of Coal - 20 Mile Haul
Payload: 27 metric tons (30 tons) of Coal

Source	Air Emissions kg (lb)/trip	
Loading	14	(30)
Unloading	14	(30)
Fugitive emissions, in transit (0.05%)	27	(60)

Ref. 5-6.

Coal Storage Piles

Coal storage refers to over 98×10^6 metric tons (108×10^6 tons) of coal stored in 1973 at electric generating plants, coke plants, and industrial sites in the U.S. waiting to be used as fuel. There are approximately 950 facilities maintaining coal storage piles. The EPA estimates that the amount of coal stored is increasing at the rate of 3.8 percent per year.

Coal storage piles are open sources of atmospheric emissions of fugitive dust particulates. The emissions from a representative coal pile (95,000 metric tons or 106,000 tons) average about 610 kg/yr of coal dust. The national emission burden from coal storage piles is 630 metric tons/yr (690 tons/yr) or 0.00048% of total national particulate emissions. No state has an emission rate more than 0.0026% of the state's total particulate emissions.(5-7)

There are essentially no particulate control technologies applied to coal storage piles. However, there are some inadvertant practices that reduce particulate emissions from coal storage piles. These include storing the coal outside where rain or snow keep the coal moist and less subject to wind erosion. Also, receiving coal in a moist state from cleaning plants reduces emissions. The intentional practice of coating coal piles with tar derivatives to prevent spontaneous combustion yields the additional benefit of reducing fugitive emissions.

Possible methods for reducing particulate emissions in the future include storage of coal in a pit or silo to reduce its exposure to the wind or to use novel coating liquids that suppress dust entrainment, not dissimilar from the tar derivative used presently.

Radionuclides in Coal and Its Combustion Products

Radioactive elements may be found in coal. Concern over the amount of radioactivity in coal has grown because of the increased amount of coal that will be used to fuel electric generating plants by 1985 (projected annual usage - 1.2 billion tons) as mandated by the National Energy Plan as submitted to Congress in April, 1977.

General

Beck, et al.,(5-8) review data regarding the radionuclide content of coal, ash, and released fly ash from coal-fired power plants. In general, the mean values for uranium, thorium, and potassium concentrations in coal are less than their average concentrations in the earth's crust. Occasionally, very high concentrations of uranium, among other radionuclides, can be found in various coal deposits in up to uranium ore grade concentrations (0.1%). This is the exception and usually occurs in low grade coal such as lignite. Most of these pockets of uraniferous coal are in the west.

Data on radionuclide concentrations in selected coals (as mined) are presented in Table 5-8. The mean values for all coals were 1.7 ug/g for natural uranium, 4.5 ug/g for natural thorium, and 1700 ug/g for potassium, corresponding to activity concentrations for uranium-238, thorium-232, and potassium-40 of 0.6, 0.5, and 1.4 pCi/g, respectively. It should be noted that radionuclides in coal vary within the seam, mine, locality, and region.

Table 5-9 reviews the data on radioactivity in ash samples collected from power plants in the U.S. by different investigators. With the exception of radioactive gases, the radionuclides in the ash will be partitioned between the bottom ash and fly ash. Certain trace elements tend to concentrate in the smaller fly ash particles which have large surface-to-volume ratios. Lead and polonium exhibit

TABLE 5-8

Uranium, Thorium, and Potassium Concentrations in Coal as Mined
(Fraction of Dry Weight)

Region (Type)	# Samples	U (ug/g)			Th (ug/g)			K (g/100g)		
		Range	Geo. Mean	Mean	Range	Geo. Mean	Mean	Range	Geo. Mean	Range
Pa., Anthracite	53	0.3-25.2	1.2	1.5	2.8-14.4	4.7	5.4	.019-1.5	.16	.24
Appalachian, b.	331	<0.2-10.5	1.0	1.4	2.2-47.8	2.8	4.9	.008-2.4	.13	.23
Midwest, b.	143	0.2-43	1.4	3.3	<3-79	1.6	5.2	.011-.53	.11	.16
N. Gt. Plains, sb,b.	93	<0.2- 2.9	0.7	0.9	<2-8.0	2.4	2.7	.006-.37	.03	.04
Gulf Coast, Lignite	34	0.5-16.7	2.4	3.2	<3-28.4	3.0	8.3	.012-1.3	.15	.30
Rocky Mt., b, sb.	134	<0.2-23.8	0.8	1.6	<3-34.8	2.0	3.6	.003-1.7	.03	.08
Alaska, sb.	18	0.4- 5.2	1.0	1.2	<3-18	3.1	4.4	.016-.87	.08	.12
Ill Basin	56 (113 K)	0.31-4.6	1.3	1.5						
Appalachian	14 (23 K)	0.4-2.9	1.3	1.5	0.71-5.1	1.9	2.1	0.04-0.56	.16	.17
Western	22 (29 K)	0.3-2.5	1.0	1.2	1.8-9.0	4.0	4.5	.06-.68	.21	.25
					0.62-5.7	1.8	2.3	.01-.32	.03	.05
Western	19	0.11-3.5	0.85	0.9	-			-		
All Samples	910 (983 K)		1.04	1.74		2.40	4.47		.13	.17
		Typical Range		Avg.	Typical Range		Avg.	Typcial Range		Avg.
Soil		0.9-4.0		1.8	2-12		6	.12-2.5		1.3
Rocks		0.5-5		2.7	1.6-20		9.6	0.3-5		2.1

---

sb. = Subbituminous b. = Bituminous

Ref. 5-7.

TABLE 5-9

Radioactivity in Ash Samples Collected From Power Plants in the U.S*

Origin	No. of Samples	Sample	Radionuclide Content - pCi/g U-238(U-234)	Ra-226	Pb-210	Po-210	Th-232(Th-228)	Ra-228	K-40
Western U.S.	8	FA	2.3(1.4-2.8)	-	-	-	4.7(2.4-6.7)	-	6.1(1.2-16.2)
Appalachian & Midwest	14		2.2(1.7-6.5)	-	-	-	4.9(1.4-7.5)	-	16.6(9.4-27.8)
Appalachia	6	FA	-	3.8(2.1-5.0)	-	-	2.6(2.1-3.3)	2.4(1.8-3.1)	-
Western U.S.		FA	1.9	2.3	1.4	-	1.7	1.7	8.1
Western U.S.		BA	1.5	1.9	0.6	-	1.5	1.5	6.8
Western U.S.		FA	3.5	2.9	2.2	-	2.4	2.4	6.3
Western U.S.		BA	2.8	2.5	0.8	-	2.2	2.1	6.2
Western U.S.		FA	3.6	3.0	2.8	-	2.5	2.5	6.2
Western U.S.	4	SA	5.4-12	3.3-5.9	4.3-17	-	2.8-3.3	2.7-4.2	7.0-7.4
Appalachia	6	FA	-	1.9(1.0-3.3)	-	-	1.4(0.4-2.0)	-	21.4(16.5-28.6
Wyoming		FA	4.3	-	5.8	5.3	-	-	-
Wyoming		BA	2.6	-	5.6	5.0	-	-	-
Wyoming		FA	-	0.8	10.5	-	-	-	-
Wyoming		BA	-	0.6	1.0	-	-	-	-
Appalachia		FA	-	2.8	-	-	1.2	1.2	10.7
Ill., Ky.		FA	3.4	-	-	-	2.2	-	16
Pa. bitum.		FA	2.3	2.3	-	-	2.1	-	18.9
Pa. bitum.		BA	1.8	1.6	-	-	1.4		12.6
Appalachia		FA	2.6	2.5	-	-	2.4		19.3
		Soil	0.7	0.7	≥ 0.7	≥ 0.7	0.7	0.7	10

---

* Where more than one value was reported the mean, range, and number of samples is shown. Most of the other values shown also represent the mean of composite or duplicate analyses. FA represents collected fly ash, SA escaping fly ash, and BA bottom ash. The SA values are the range for 4 different size fractions. The average activities of typical soil are also shown for comparison. Ref. 5-7.

the greatest concentration enrichments in released fly ash. Uranium shows modest enrichment; thorium and potassium exhibit less. Radium-226 and radium-228 exhibit a slight enrichment in fly ash over the bottom ash. It is assumed that all or most radon-222 gas in the coal is released upon combustion and escapes from the plant. Radon-220 is neglected because of the short half-life involved.

Western vs. Eastern Coal

There is some question about how much radioactive material is contained in western versus eastern coal. In The Radiologcal Quality of the Environment in the U.S. in 1977,(5-9) it is stated that "in the United States, significantly higher (factors of 10 to 100) uranium concentrations in coal are generally found in the west (principally North and South Dakota, Montana, Wyoming, New Mexico, Idaho, and Nevada) as opposed to eastern Appalachian deposits." Beck, et al., in contrast, states that with the exception of the uraniferous coals*, "western coals taken as a whole, contain lesser quantities of all types of trace elements, including radionuclides, than other coals."(5-8) Beck claims that an incorrect impression of higher radioactivity in western coals, as compared to eastern, has resulted from the existence of these uraniferous deposits.

Heating Value vs. Radionuclide Release

Coal is usually ranked by its BTU per pound heat value. Western coal generally has a lower BTU heat value; eastern coal has a higher BTU heat value. Consequently, more western coal is required to produce the same amount of electricity given equal power plant design and operating values. More radionuclides will enter the atmosphere through the additional coal required to produce the same amount of electricity if as a first approximation, it can be assumed that radionuclides are uniformly distributed in coal across the nation. Table 5-10 gives representative heat contents for the different ranks of coal.

---

* Most of which are found in the lignites of the northern Great Plains and constitute 0.1% of the U.S. Western coal reserves.

TABLE 5-10

Coal Heat Content

Rank	Heat Content	Principle Mining Locations
Anthracite	14,000 BTU/lb	Pennsylvania, Alaska
Bituminous	13,100 BTU/lb	Appalachian and Central States, Colorado, Utah, Alaska, Wyoming, New Mexico, Missouri, Texas
Subbitumious	9,500 BTU/lb	Northern Great Plains States, New Mexico, Washington, Alaska, Colorado
Lignite	6,100 BTU/lb	Montana, North Dakota, South Dakota, Arkansas, Texas

Ref. 5-10.

Coal and Ash - Radionuclide Studies

There exist nationwide variations in the radionuclide contents of coal combined with widespread variations in coal combustion characteristics and power plant combustion and exhaust gas cleaning processes. This can result in a wide range of radionuclide distributions in the coal combustion products. Several studies are therefore considered that provide insight to the fate of radionuclides in power plant coal combustion. These studies were chosen on the basis of their thoroughness, quality, and applicability to the subject under discussion.

Study No. 1

Klein, et al., (5-11) traced the pathways of thirty-seven trace elements through coal-fired power plants, using the T.A. Allen Steam Plant in Memphis, Tenn. (part of TVA) as a model. The Allen Steam Plant has three air pollution control units; one was studied. The unit was a high efficiency electrostatic precipitator. Elements in coal, fly ash, slag and combustion gases from the large 870 MWe cyclone-fed power plant were examined. Of the elements analyzed, K, Th, Pb and U are of interest to this study. Data on these elements are, therefore, presented in Table 5-11.

It can be seen from the table that potassium and thorium show little preferential partitioning between the slag and fly ash, while lead shows a definite concentration on fly ash. The two sets of uranium values are conflicting, but as a rough approximation the uranium is not strongly partitioned either way.

Klein, et al., describe their observations of the behavior of trace elements and the reasons for preferential partitioning. They believe that the behavior of these trace metals are a function of the initial chemical state of the metals in coal. Trace metals

TABLE 5-11

Selected Trace Element Flows Through A Coal Fired Power Plant[a]

Element[b]	Elemental Flow (g/min)			
	Input	Output		
	Coal	Slag	Fly Ash	Total[c]
K 72	2700	1550	850	2400
K 73	2260	1330	1480	2810
Pb 72	9.2	0.6	7.8	8.4
Pb 73	7.2	0.5	5.9	6.4
Th 73	3.1	1.3	1.5	2.8
U 72	3.0	2.0	1.1	3.1
U 73	3.2	1.3	2.2	3.5

---

a. Ref. 5-11. Data are for an 870 MWe plant.
b. Number following the element symbol is the year of the sample run.
c. Sum of slag and fly ash values.

in coal exist as part of aluminsilicates, organic sulfides, and organic complexes. Aluminosilicates are not decomposed upon combustion. They tend to melt and coalesce to form the slag and fly ash. The aluminosilicates should thus tend to be incorporated into the slag and fly ash.

Sulfide minerals and organometallic complexes are decomposed during the initial stages of combustion, in which the conditions within a coal particle and within the immediate vicinity are probably reducing. The contained trace metals should then be released as volatile species in the gas stream when the coal is burned. These initially volatized or dispersed metals may then be oxidized to form less volatile species. The less volatile species may then condense or be sorbed onto fly ash as the flue gas temperature decreases. Condensation of metals on the slag should be minimal because the contact time between the flue gas and the slag is extremely small and the temperature is very high.

Klein, et al., believe that three classes of partitioning behavior are observable in the combustion of coal.

Class I: Some elements (includes thorium) are readily incorporated into the slag. They seem to be partitioned almost equally between inlet* fly ash and slag with no tendency to concentrate on the outlet* fly ash.

Class II: Some elements (includes lead) incorporate poorly into the slag and concentrate in the inlet fly ash and even more strongly on the outlet fly ash as compared to the slag.

Class III: The elements Hg, Cl, and Br, remain essentially completely in the gas phase.

Unclassed: Some elements (includes uranium) could not be definitely assigned to a class on the basis of the data collected. They exhibit behavior intermediate between Classes I and II.

---

*Inlet and outlet refer to the direction of boiler exhaust gas flow with respect to the gas cleaning device, which in this case is an ESP.

This proposed scheme is consistent with geochemical principles. Elements can be classified as being lithophiles or chalcophiles according to their tendency to be associated with aluminosilicates or sulfide minerals, respectively. All of the Class I elements are lithophiles in crustal rock except Co and Fe, which exhibit both lithophilic and chalcophilic behavior. All of the Class II elements are chalcophiles in crustal rocks except copper, which exhibits both lithophilic and chalcophilic behavior. Class III elements are very volatile and may not exhibit lithophilic or chalcophilic behavior. Of the unclassed elements Na, Cs, U and V are lithophiles and Cr and Ni exhibit lithophilic and chalcophilic behavior.

One of the results of the Klein study of the Allen Steam Plant in Memphis indicates that electrostatic precipitators can be made efficient for the removal of most elements, (not volatiles such as Hg), but like scrubbers, are in varying degrees less efficient for removing elements that concentrate in the very fine particulates (0.1-0.5 microns). Many of the elements observed will collect on the ash (bottom and/or fly) and be disposed to ash ponds from which they may be removed by weathering or biological processes. Thus, it appears that the disposition of some of the potentially toxic metals and radioactive elements in coals will depend upon how the ashes are stored or disposed.

Study No. 2

Coles, et. al.,(5-12) studied the chemical fractionation of the natural radionuclides in coal during combustion and inferred the behavior of the natural radionuclides from deposition in the coal through combustion and emission at the power plant. Two plants, A & B, using western coal were the sites where samples of coals, fly ash, and bottom ash were collected. One plant was equipped with a cold-side electrostatic precipitator (ESP), and the other was equipped with a venturi scrubber and two ESPs. Radiometric analyses of the collected samples are presented in Table 5-12.

TABLE 5-12

Contents of Various Radionuclides in Coal, Bottom Ash, and Fly Ash[a]

	ppm			pCi/g						
	U	Th	K	K-40	Th-238	Ra-228	Pb-210	Ra-226	U-238	U-235
Plant A[b]										
Coal	0.71	1.6	860	0.73	0.17	0.17	0.26*	0.21	0.24	0.012*
ESP Fly Ash	5.6	15	9440	8.1	1.7	1.7	1.4*	2.3	1.9	0.093
Bottom Ash	4.6	14	7900	6.8	1.5	1.5	0.58*	1.9	1.5	0.072
Plant B[c]										
Coal	2.6	5.0	1660	1.4	0.56	0.55	0.68*	0.64	0.85*	0.037
ESP Fly Ash	11	22	7400	6.3	2.4	2.4	2.2	2.9	3.5*	0.14
Bottom Ash	8.4	19	7200	6.2	2.2	2.1	0.84*	2.5	2.8*	0.11
Scrubber Ash	11	22	7200	6.2	2.5	2.5	2.8*	3.0	3.6	0.14
Plant B[c]										
Post-ESP (stack) fly ash (mmd)[d]										
18.5 um	16	25	8200	7.0	2.8	2.7	4.3	3.3	5.4	0.17
6.0 um	20	31	8600	7.3	3.3	3.5	10	4.6	6.8	0.28
3.7 um	30	36	8600	7.4	3.3	4.0	14	5.3	10	0.39
2.4 um	36	38	8100	7.0	3.3	4.2	17	5.9	12	0.50

---

a. Errors 20% with*, 10% without* (1σ error from the mean or counting statistics, whichever is larger).

b. Samples from Plant A; input coal contains 11.3% H_2O, 9.2% ash, and 0.52% sulfur.

c. Samples from Plant B; input coal contains 6.8% H_2O, 23.2% ash, and 0.46% sulfur.

d. mmd = mass median diameter determined by centrifugal sedimentation.

Ref. 5-12.

The behavior of the naturally occurring radionuclides, potassium-40, lead-210, radium-226, thorium-228, radium-228, uranium-235, and uranium-238, during combustion in coal fired plants indicates significant to at least slight concentration enrichments in the finer stack fly ash particles (post-ESP) for all the elements observed. Table 5-13 presents the calculated enrichment factors relative to the input coal after normalizing to the potassium-40 concentration.* The values range from 5.0 for lead-210 to 1.2 for thorium-228. Uranium-235 and uranium-238 enrichment factors both equalled 2.8. Radium-226 and radium-228 enrichment factors were 1.9 and 1.6. In general, the finer stack fly ash particles (post-ESP) show a very strong increase in enrichment factors with decreasing particle size. Lead-210 shows the greatest small particle preference in the size-classified (post-ESP) fly ash of any of the nuclides measured. This effect is consistent with the depletion of lead in the larger-sized ESP fly ash.

The uranium-238 natural radioactive decay-chain series was found to be in secular equilibrium in the coal samples but not in the ash samples. This is expected because during the combustion process a potential exists for decay chain disequilibrium, since many of the daughter radionuclides have quite different chemical and physical characteristics. The daughter radionuclides that emit gamma rays can be observed simultaneously, and the degree of disequilibrium can be determined.

---

*"Enrichment factors relative to the input coal were calculated for the radionuclide contents observed. The enrichment factor (EF) is defined as the ratio of the concentration of a radionuclide (X) and ^{40}K in the sample divided by the corresponding ratio in the input coal.

$$EF = \frac{[X]\ sample/[^{40}K]sample}{[X]coal/[^{40}K]coal}$$

This effectively normalizes the apparent enrichment resulting from loss of carbon during the combustion process. Potassium-40 is used in this normalization because its concentration remains more or less constant in all samples; hence, it was assumed to be a tracer for the alumino-silicate-dominated ash matrix."(5-12)

TABLE 5-13

Radionuclide Enrichment Factors Relative to Input Coal and Normalized to ^{40}K[a]

	Th-228	Ra-228	Pb-210	Ra-226	U-238	U-235
			Plant A[b]			
ESP fly ash	0.89	0.90	0.48*	1.0	0.71*	0.70*
Bottom ash	0.96	0.97	0.24*	0.99	0.70	0.64*
			Plant B[c]			
ESP fly ash	0.96	0.98	0.74*	1.0	0.94*	0.85*
Bottom ash	0.91	0.89	0.29*	0.90	0.76	0.73*
Scrubber ash	1.0	1.0	0.95*	1.1	0.97	0.88*
			Plant B[c]			
Post-ESP fly ash (mmd)[d]						
18.5 um	1.0	1.0	1.3	1.1	1.3	0.94
6.0 um	1.1	1.2	3.0	1.4	1.6	1.4
3.7 um	1.1	1.4	4.1	1.6	2.3	2.0
2.4 um	1.2	1.5	5.0	1.9	2.8	2.8

---

a. Errors 20% with*, 10% without* (1σ error from the mean or counting statistics, whichever is larger).

b. Samples from Plant A; input coal contains 11.3% H_2O, 9.2% ash, and 0.52% sulfur.

c. Samples from Plant B; input coal contains 6.8% H_2O, 23.2% ash, and 0.46% sulfur.

d. mmd = mass median diameter determined by centrifugal sedimentation.

Ref. 5-12.

Both uranium-235 and uranium-238 show significant depletion in the ESP fly ash from Plant A (low-ash coal) and the bottom ash from both plants. The fly ash is not nearly as depleted in those uranium isotopes from Plant B (high-ash coal). Thorium-228 and potassium-40 show little fractionation. Lead-210 shows a definite depletion in the bottom ash and the ESP fly ash.

Coles, et al., describe the behavior of the natural radioactive-decay series throughout the coal deposition, combustion, and emission system. As organic matter accumulated, inorganic sediments also were deposited. The inorganic sediments contained aluminosilicate minerals (they later comprise the coal fly and bottom ash). This is the source of thorium-232, potassium-40 and part of the silicate associated uranium. Over time both the organic and inorganic matter were buried. Coal metamorphism took place. Ground and surface waters infiltrated the overburden invading the coal seams. The water contained uranium as soluble uranyl carbonate salts and varying amounts of soluble silica. The coal absorbed the uranium, reducing it to uraninite or coffinite, depending upon the amount of silica in the water.(5-12)

When the coal is burned, most of the aluminosilicate minerals (mostly clay) drop out as slag. Most thorium and radium remain with the slag. Lead-210 is volatile and goes up the stack with the flue gases. The uranium that was mineralized as coffinate remains with the bottom ash. That which is uraninite continues along with the fly ash in the flue gases. Uranium and lead condense out on the finer fly ash particles. Those particles that escape capture by an emission control device were very enriched in lead-210 relative to the coal, and moderately enriched in uranium-235 and uranium-238 relative to the coal. There was slight enrichment for radium-226, (probably that associated with uraninite) radium-228 and thorium-228. The thorium is proabably associated with fine zicron grains. The mineralogical or chemical form in which the radionuclides exist in coal thus has an important effect on their combustion and emission characteristics. (5-12)

The wet scrubber in this study was more efficient than the ESP for bulk fly ash removal, retaining more ash by weight than the ESP. The scrubber, however, releases more of the submicron particles to the air than the ESP.

Study No. 3

Kreiger and Jacobs (5-13) performed gamma spectrometry on a number of types of coal and combustion products. The gamma-ray activities in the coals, ashes and sludges were found to be a function of source and type of fuel combusted.

Table 5-14 presents a radiochemical analysis of coal and its by-products in pCi/g. Thorium-228 and thorium-232 are enriched the least in the fly ash and bottom ash of all the isotopes. The others are enriched in varing amounts.

Summary

In summary, the following general conclusions can be stated concerning the fate of radionuclides in power plant coal combustion.

1. Radionuclides exist in coal in varying amounts depending upon the geological formation and deposition of the coal.

2. There is some disagreement concerning the issue of whether eastern or western coal has a greater concentration of radionuclides.

3. In general, the BTU heat value of eastern coal is higher than that of western coal. Therefore, more western coal than eastern coal must be burned to produce the same energy, thus yielding greater quantities of combustion products.

TABLE 5-14

Radiochemical Analysis of Coal and Coal By-Products

	Sample	Radionuclide Content (pCi/g)						
Date	Identification	Ra-226	U-234	U-235	U-238	Th-238	Th-230	Th-232
6/76	E. Ky. Coal	0.28±0.01	0.54±0.07	0.03±0.01	0.51±0.07	0.40±0.04	0.46±0.03	0.30±0.03
	W. Ky. Coal	1.98±0.01	0.80±0.10	0.04±0.01	0.78±0.03	0.21±0.03	0.71±0.05	0.19±0.02
	W. Ky. Fly Ash	7.0±0.1	6.3±1.1	0.33±0.09	8.6±1.1	1.9±0.1	6.5±0.3	1.8±0.1
	W. Ky. Bottom Ash	5.0±0.1	5.6±0.8	0.22±0.07	5.5±0.8	1.9±0.4	6.0±0.7	1.6±0.3
6/77	E. Ky. Coal	0.46±0.01	0.56±0.16	0.07±0.02	0.58±0.12	0.60±0.08	0.61±0.13	0.39±0.09
	W. Ky. Coal	0.72±0.01	0.92±0.10	0.05±0.02	0.92±0.10	0.34±0.04	0.85±0.05	0.27±0.03
	W. Ky. Fly Ash	3.8±0.1	4.2±0.5	0.20±0.07	4.4±0.5	1.8±0.2	4.5±0.3	1.57±0.18
	W. Ky. Bottom Ash	3.1±0.1	2.7±0.4	0.09±0.04	2.7±0.3	1.7±0.2	2.7±0.3	1.3±0.2

Ref. 5-13.

4. Radionuclides tend to partition between the fly ash and bottom ash with the fine submicron particulates of the fly ash exhibiting the highest radionuclide concentrations.

5. The geochemical classification of the elements yields predictions about radionuclides in coal and from these predictions the behavior of radionuclides after combustion can be explained. Lithophiles (including thorium) tend to incorporate into the slag. Chalcophiles (including lead) concentrate in the fly ash. Other elements remain in the gas phase. Still others (such as uranium) tend to exhibit behavior between lithophiles and chalcophiles.

Radionuclides and Control Devices - Natural Gas and Fuel Oil Fired Electric Generating Plants

This section of the report briefly reviews particulate control technology used at natural gas or petroleum burning electric generating plants. Both petroleum and natural gas are relatively free of particulate emissions when burned to produce electricity. Hence, there is a diminished emphasis on natural gas and petroleum fired plants as opposed to coal fired plants where emissions are greater.

The following is a brief description of the amounts and kinds of radionuclides found in natural gas and fuel oil combustion emissions.

Natural Gas

Power plants fueled by natural gas are generally characterized as having no emission control devices and little solid or liquid waste. Scant data exist on the amounts of radionuclides that are emitted after the combustion of natural gas. Natural gas contains radon as a result of the emanation of radon from radium bearing geological strata. Radon concentrations in natural gas have been found to average approximately 20 pCi/1.(5-19) Based on this average, a 4 unit model 2316 MW(e) power plant, would yield a stack release rate of 295 mCi of radon per day at full power.(5-15)

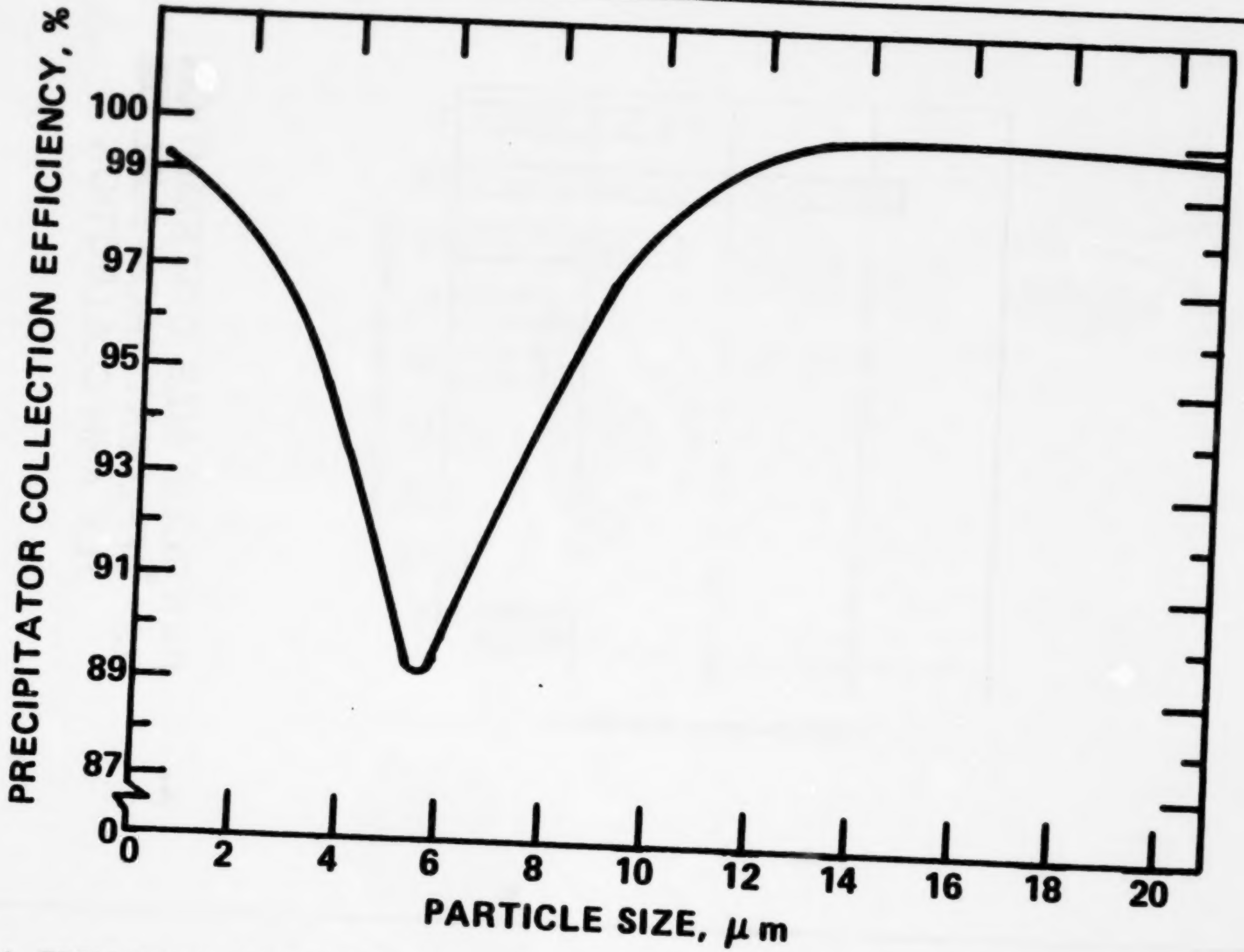
Fuel Oil

Petroleum contains many trace elements, including uranium, thorium and their radioactive daughters. Generally, concentrations of trace elements in fuel oils and their corresponding combustion products (fly ash) are lower by at least an order of magnitude as compared with coals. For example, the radioactive trace element radium-226 is present in fly ash from an oil-fired plant in concentrations averaging approximately 21 times less than the concentration of radium-226 in fly ash from coal-fired plants.(5-14) Data on the natural uranium content of fuel oil has been published by the EPA (5-15), which currently uses 0.002 ppm uranium by weight as a median value. The total ash content of fuel oil is approximately 0.1 percent by weight.

Particle or size distribution of the fly ash is a very important parameter with regard to control technology. This distribution depends upon the degree of atomization of the oil, efficiency of mixing, furnace temperature and design, and specific plant design. Fuel oil ash is, however, generally classified as a very fine particulate. Ashes collected from stack gases from oil combustion usually vary from less than 0.01 micron to 40 microns in diameter.

Oil-burning plants often do not employ control devices. ESPs appear to be the most common, if a device is used. One characteristic of fuel oil ash pertinent to ESP controls is the low electrical resistivity relative to most low sulfur fly ash from coal. Therefore, electrostatic precipitators will likely require higher operating current when collecting oil fly ash as compared to coal fly ash.

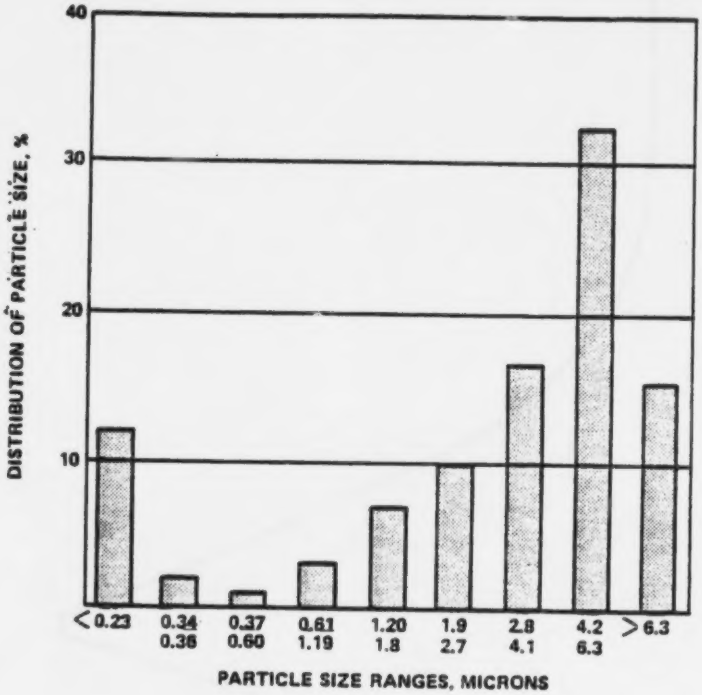
ESP fractional collection efficiency data for fuel oil ash is shown in Figure 5.1. The curve, which is derived from particle size analyses at the inlet and outlet of an electrostatic precipitator collecting oil ash, shows that the minimum collection efficiency (about 89 percent) occurred at 5.5 microns. The collection efficiency of both fine and coarse particles was well over 99 percent. The resultant particle size distribution of the ESP effluent is presented in Figure 5.2.



FUNCTIONAL EFFICIENCY CURVE CALCULATED FROM INLET AND OUTLET SIZE DISTRIBUTION FOR AN ELECTROSTATIC PRECIPITATOR COLLECTING OIL ASH

Source: Reference 5-16

FIGURE 5.1



PARTICLE SIZE DISTRIBUTION:
ESP EFFLUENT FROM FUEL OIL
FLY ASH COLLECTION

SOURCE: REFERENCE 5-16

DAMES & MOORE

FIGURE 5.2

Particulate Control Device Evaluation - Electric Generating Stations

Introduction

Many different types of technologies are utilized to control airborne emissions of particulates. Electrostatic precipitators, fabric filters and scrubbers are discussed fully in the Appendices. These technologies are the most commonly utilized in the electric utility industry. Following a brief description of each device, an evaluation of the control devices will be made using the criteria of efficiency, costs, energy use and residuals.

Electrostatic Precipitators

The process of electrostatic precipitation involves the removal of dust or liquid aerosol from a gas stream by imparting an electric charge to the contaminant and then passing the stream through an electric field. ESPs are used for varying purposes such as recovering precious metals, or removing fly ash from coal fired boiler flue gas. The principal uses of ESPs today are in facilities where high collection efficiencies of small particles are required from large volume effluent streams. The efficiencies generally range from 98% to 99+% under suitable conditions. Operating costs and energy use of ESPs are comparable to scrubbers installed on similar capacity plants, and they usually discharge solid effluents, the magnitude of which depends on the operating conditions.

Fabric Filters

Fabric filters (baghouses) are utilized for the collection of dry particulate effluents of suitable chemical compositions. The fabric filter removes particulate matter from the gas stream by the particulates impinging upon and then adhering to the filter material. Over time, the deposit of particulates becomes greater and acts as a filtering media. When the deposit becomes so heavy that the pressure to force gas through the filter is excessive, the fabric filter must be cleaned. This is often done by shaking the bags so that excess deposits fall into an underlying hopper.

The collection efficiencies given by vendors are usually in the range of 98% to greater than 99.99% for submicron particles as well as for particles larger than 1.0 microns. Energy requirements are generally less as compared to ESPs or scrubbers, while maintenance costs are usually higher.

Scrubbers

Scrubbers are utilized to remove particulates from gaseous streams through the physical and chemical interaction between the particulates and a scrubbing medium such as water. Depending on the scrubbing medium, scrubbers can also remove gaseous radioactive effluents. There are many different kinds of scrubbers (with the associated vendor mass efficiencies) such as baffle scrubbers (about 93%), wet impingment scrubbers (about 98%) and venturi scrubbers (about 99+%). The efficiencies depend on many factors such as the pressure drop, particulate load, system design, and effluent chemical composition. Scrubbers require about three times as much energy to operate as corresponding fabric filters and usually discharge liquid effluents, the magnitude of which depends on the operating conditions.

Particulate Collection Efficiencies

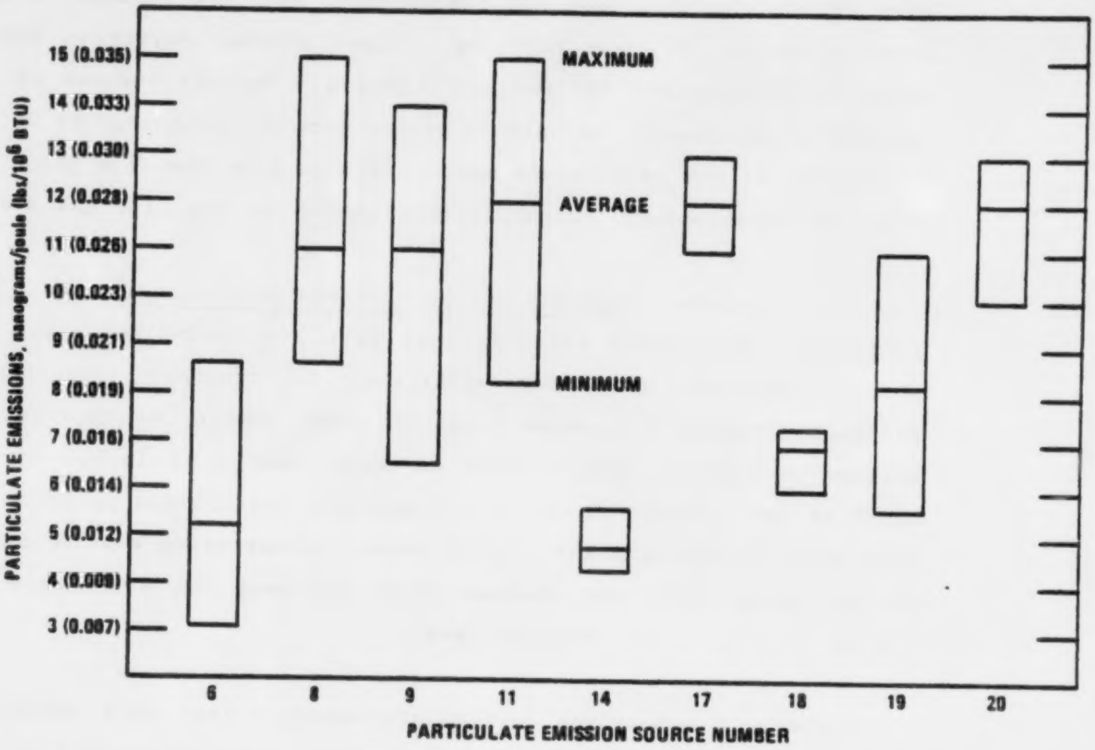
Electrostatic Precipitators

A number of factors determine ESP performance and efficiency. They include ash characteristics, ESP size, specific collection area (SCA), gas flow rate and temperature, moisture content, rapping control design, fly ash handling system, thermal expansion design, maintenance practices and gas conditioning. For the purpose of this section of the report, efficiency of the control technology is defined as a ratio of the particulate matter removed from the flue gas stream over the total amount of particulate matter in the flue gas stream.

EPA document, Electric Utilities Steam Generating Units, (5-17) summarizes particulate emission test data for coal-fired steam generators equipped with high efficiency electrostatic precipitator systems. Figure 5.3 shows that for best controlled sources, ESP systems controlled particulates to less than 0.03 lb/10^6 Btu (13 ng/J) of heat input. Table 5-15 summarizes particulate emission test data on difficult emission control cases, illustrating that in all but one of those cases the devices could not meet the 0.03 lb/10^6 Btu (13 ng/J) particulate emission level.

Table 5-16 summarizes particulate emission test data gathered by the EPA in a series of tests for coal-fired steam generators equipped with high efficiency electrostatic precipitators. The test results show that the emissions range from 0.007-0.05 lb/10^6 Btu (3-22 ng/J). All tests run would meet present and proposed standards.

Fine particulates (below 2 μm) present special problems. They are within the respirable range and, thus, can be associated with health problems. Research indicates that radionuclides tend to concentrate on fine particulates in the flue gas stream. (Refer to the research studies cited in Radionuclides in Coal in this report).



EMISSION TEST DATA

FOR ELECTROSTATIC PRECIPITATORS

(COAL-FIRED STEAM GENERATORS)

SOURCE: REFERENCE 5-17

FIGURE 5.3

TABLE 5-15

Summary of Data on Difficult Electrostatic Precipitator Control Cases For Pulverized Coal-Fired Steam Generators

Unit Identification No.	Unit Size	ESP Type	Coal Sulfur Content	Specific Collection Area (SCA)		Average Control Effectiveness	
	(MW)		(%)	(m^2/m^3-sec)	(ft^2/1000 ACFM)	(ng/J)	(lb/10^6 Btu)
2	800	Hot	0.5	60.4	307	13.7[a]	0.032
3	800	Hot	0.5	60.4	307	15.5[a]	0.036
22	330	Hot	0.9	57.5	292	17.2[a]	0.040
12	250	Cold	0.7	158	803	19.8	0.046
13	250	Cold	0.7	158	803	20.6	0.048
6	500	Cold	0.5	174	884	4.0[a]	0.0094
21	680	Cold	0.5	151	767	13.6	0.032

---

a = EPA Method 5.
b = EPA Sponsored Test.

Ref. 5-17.

TABLE 5-16

Summary of Data on Pulverized Coal-Fired Steam Generator High Efficiency Electrostatic Precipitator Systems

Unit Identification No.	Unit Size	ESP Type	Coal Sulfur Content	Specific Collection Area (SCA)		Control Effectiveness	
	(MW)		(%)	(m^2/m^3-sec)	(ft^2/1000 ACFM)	(ng/J)	(lb/10^6 Btu)
1	500	Cold	0.6	96.1	488	18-20[a]	0.042-0.046
2	800	Hot	0.5	60.4	307	12-18[a]	0.027-0.043
3	800	Hot	0.5	60.4	307	14-16[a]	0.033-0.038
4	570	Cold	1.9	57.3-59.1	291-300	14-17	0.032-0.040
5	570	Cold	1.9	52.8-54.3	268-276	10-18	0.024-0.043
6	500	Cold	0.5	174	884	3.0-8.6[a]	0.007-0.020
7	657	NG	1.1	NG	NG	16-17[a]	0.037-0.039
8	46	NG	1.4	NG	NG	9.0-15[a]	0.021-0.034
9	46	NG	1.4	NG	NG	6.4-14[a]	0.015-0.033
10	1300	Cold	0.9	65.9	335	17-20	0.040-0.046
11	69	Hot	1.4	NG	NG	8.2-15[a]	0.019-0.036
12	250	Cold	0.7	158	803	19-20	0.044-0.047
13	250	Cold	0.7	158	803	20-21	0.046-0.050
14	190	Hot	1.4	53.0	269	4.3-5.6[a]	0.010-0.013
15	350	Hot	0.4	NG	NG	18.9[a,b]	0.044

TABLE 5-16 (cont'd)

Summary of Data on Pulverized Coal-Fired Steam Generator High Efficiency Electrostatic Precipitator Systems

Unit Identification No.	Unit Size	ESP Type	Coal Sulfur Content	Specific Collection Area (SCA)		Control Effectiveness	
	(MW)		(%)	(m^2/m^3-sec)	(ft^2/1000 ACFM)	(ng/J)	(lb/10^6 Btu)
16	700	Hot	1.4	53.7	273	15-17[a,b]	0.034-0.039
17	141	NG	0.8	NG	NG	11-13[a]	0.026-0.030
18	187	NG	0.8	NG	NG	6.0-7.3[a]	0.014-0.017
19	411	NG	1.1	NG	NG	5.6-10[a]	0.013-0.024
20	74	NG	1.4	NG	NG	10-13[a]	0.024-0.031
21	680	Cold	0.5	151.0	767	12-17[a,b]	0.027-0.040

---

a = EPA Method 5.
b = EPA Sponsored Test.
NG = Data not given

Ref. 5-17.

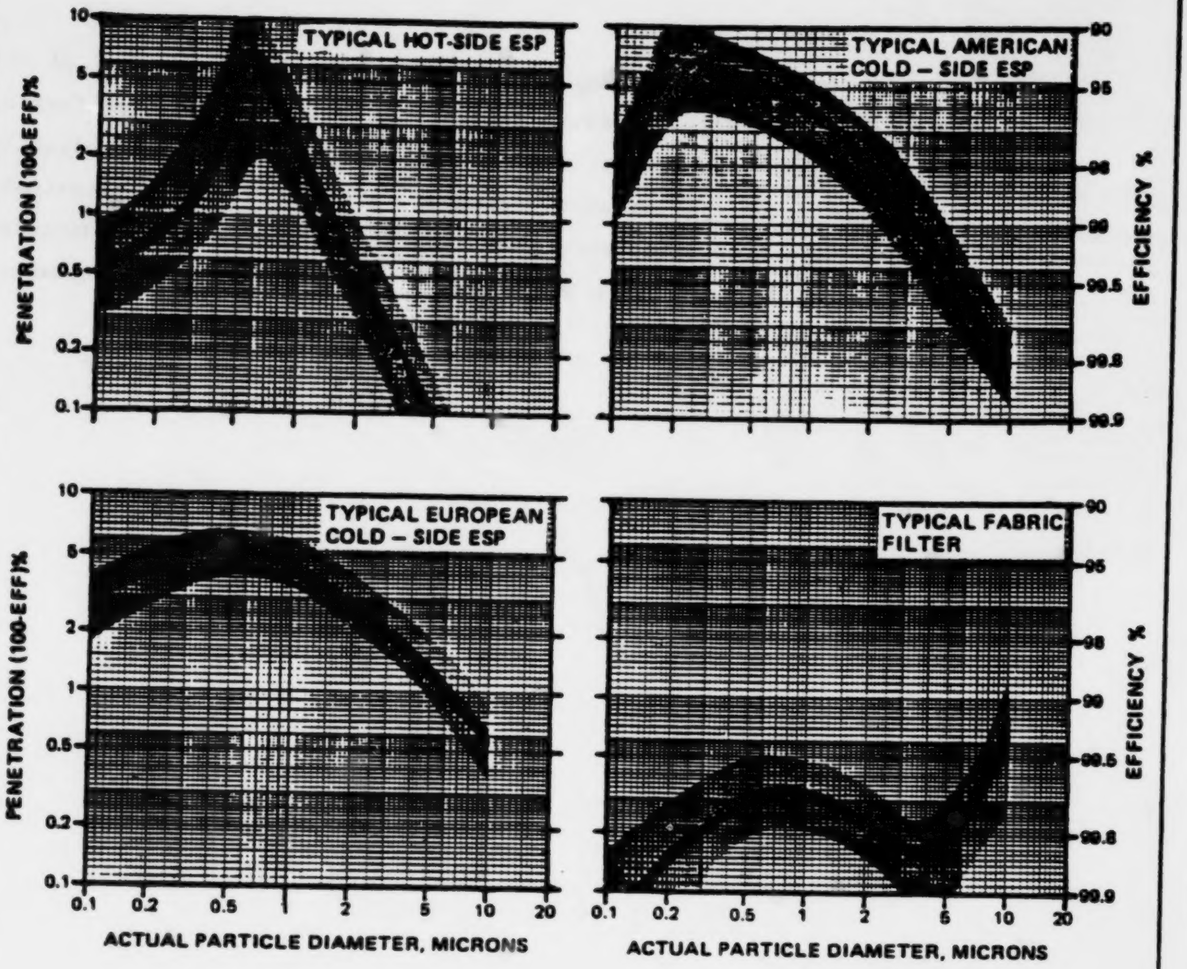
ESPs fractional collection efficiencies vary.

> "Recent field measurements on full-scale electrostatic precipitators collecting fly ash from electric utility boilers have shown that fractional collection efficiencies generally follow theoretical predictions with decreasing particle size to some minimum at around 0.2 to 0.5 um, followed by an increase in collection efficiency of smaller particles, down to about 0.05 um".(5-18)

Southern Research Institute conducted a survey of information on fine particulates. They stated that:

> "sets of fractional efficiency data indicate that existing ESPs operating without severe resistivity limitations are capable of collecting submicron particulate matter in the size range 0.05-2.0 um with an efficiency of at least 90%. There is theoretical basis for projecting minimum collection efficiencies of the order of 99% with specific collecting areas of 300 ft^2/1000 cfm under very favorable electrical conditions. This would correspond to a minimum effective migration velocity of about 8 cm/sec. Increasing the plate area would, of course, increase the obtainable efficiency."(5-18)

For ESPs and fabric filters, the efficiency changes with the size of the particle to be captured. Figure 5.4 shows typical fractional efficiencies. ESPs generally perform less efficiently for 2 to 5 micron size particles. Fabric filters tend to become somewhat less efficient for particles larger than 10 microns, while maintaining a 99% capture rate.



TYPICAL FRACTIONAL EFFICIENCIES
FOR EXISTING COLLECTORS

Source: Reference 5-19

DAMES & MOORE

FIGURE 5.4

In summary, ESP efficiency ratings are approximately 99% if the device operates without severe resistivity problems and under favorable electrical conditions. Different types of ESPs have slightly different collection patterns. However, all seem to have approximate minimum collection efficiencies at about 0.2 to 0.5 um, with increased efficiencies for particles both smaller and larger than approximately 0.2 to 0.5 um.

Fabric Filters

Two studies of fabric filter efficiencies are presented and discussed below. In both studies fabric filter efficiencies appear to be superior to both ESPs and scrubbers.

Nucla Study

In a report entitled, Determination of the Fractional Efficiency, Opacity Characteristics, Engineering and Economic Aspects of a Fabric Filter Operating on a Utility Boiler, (5-20) the fabric filter [baghouse] of the Nucla Colorado Station of the Colorado Ute Electric Association was studied by Electric Power Research Institute. The plant is 12 MW with outlet mass concentrations of less than 0.0011 gr/ft^3. Overall collection efficiency was 99.92%.

The following conclusions were drawn from the study:

> "Overall and fractional particulate collection efficiencies obtained at Nucla indicate that fabric filtration can achieve the highest efficiency of current particulate control technologies. Overall mass emissions were 0.0035 lb/million Btu (0.001 gr/scf) at full load of 12 MW (air/cloth = 2.8 ft/min) as determined by cascade impactors."(5-20)

The baghouse in this case was relatively insensitive to varying kinds of ash coming from the boiler. During an upset, particulate emissions increased only from 0.0035 lb/million Btu to 0.005 lb/million Btu. The baghouse was an efficient collector of submicron particles. Fractional collection efficiency did not fall below 99.9 percent for particles from 0.02 to 2 um in size.

EPA Study

The EPA in Electric Utility Steam Generating Units (5-17) summarizes emission test data on industrial and utility fabric filters. The major difference between an industrial and a utility baghouse is the number of cells. Therefore, data on efficiency for industrial boiler baghouses can be applied to electric steam generators. As can be seen in Table 5-17 emissions for every case are less than 0.10 lb/10^6 Btu, and in four of the cases, emissions were less than 0.03 lb/10^6 Btu for best controlled sources. Note that only source number listings 2 and 3 are for coal-fired power plants.

In summary, fabric filters appear to be capable of controlling particulates from coal combustion to levels less than 13 ng/J (0.03 lb/10^6 Btu) at pressure drops less than 1.25 kilopascals (5 in. H_2O) and with an average bag life of two years. For detailed assumptions, refer to Electric Utilities Steam Generating Units.(5-17)

Scrubbers

The major factor influencing collection efficiency is pressure drop across the device. In venturi scrubbers, high pressure drops create smaller liquid droplets (more surface area for particulate collection) and more turbulence (better mixing of droplets and particulates), resulting in increased collection efficiencies. However, the high gas velocity results in a short contact time between the particulates and the droplets. Thus the overall collection efficiency is lower in venturi scrubbers as compared to ESP's and fabric filters under given operating conditions.

The liquid distribution system employed in a scrubber also has an effect on collection efficiency. For example, a venturi scrubber operating at low pressure drop will exhibit a slightly lower efficiency using a weir to introduce the liquid into the system as

TABLE 5-17

Summary of Data on Baghouses Applied To Coal-Fired Steam Generator Combustion Gases

Source Number	Source Type	Coal Sulfur Content	Source Size	Type of Filtration	Cleaning Method	Air-to-Cloth Ratio[d]		Pressure Drop		Effectiveness	
		%	Megawatts			ACMM/M^2	ACFM/ft^2	Kilopascals	(in. H_2O)	ng/J	(lb/10^6 Btu)
1	S	2.0	10^b	Outside-in	Reverse air	0.61-0.76	2.0-2.5	0.52-0.70	2.1-2.6	4.7^{e,f}	0.011
1	S	2.0	10^b	Outside-in	Pulse jet	0.76-0.9	2.5-3.0	0.55-1.1	2.2-4.3	9.9^{e,f}	0.023
2	PC	2.0	44^c	Inside-out	Reverse air	0.58	1.9	0.62	2.5	1.2-4.3^{e,f}	0.0028-0.0100
3	S	0.7	13^c	Inside-out	Shaking and reverse air	0.85	2.8	1.25	5.0	0.60-7.7^{e,f}	0.0014-0.0180
4	S		18^b	NG	NG	NG		NG		11.2^g	0.026
5	S		12.5^b	NG	NG	NG		NG		3.9^g	0.009
6	S		24^b	NG	NG	NG		NG		18^g	0.042
7	S		6.4^b	NG	NG	NG		NG		6.4^g	0.015
8	PC	0.5	25^b	Inside-out	Reverse air	0.69	2.26	2-2.5	8-10	15.5^{e,f}	0.036

---

a. S=Stoker, PC=Pulverized Coal.
b. Industrial boiler.
c. Utility Boiler.
d. ACMM/m^2 = actual cubic meters per minute per square meter.
ACFM/ft^2 = actual cubic feet per minute per square foot.
e. EPA Method 5.
f. EPA sponsored test.
g. Non-EPA or no data.
NG = Data not given.

Ref. 5-17.

compared to using liquid sprays. At high pressure drops, the initial distribution of liquid becomes less important because the gas stream serves as the effective distributor. However, at pressure drops below 20" w.g., initial liquid distribution is important.

Efficiency is further improved with increasing liquid to gas ratios, although once sufficient liquid is present, greater quantities are not effective.

One problem characteristic of wet scrubbers is moisture entrainment which can cause a substantial increase in emissions. Mist eliminators are therefore required for high performance. This is particularly true when the solids content of the scrubbing liquor is high. For example, the effect of escaping droplets on particulate emission is 150 times as great using 15 percent solids slurry as opposed to one with 0.1 percent solids.

In tests by the EPA published in 1978 (5-17) scrubbers were found capable of controlling particulates to a level less than 0.05 lb/10^6 Btu. Table 5-18 summarizes the data. A scrubber such as a venturi scrubber, operating at a pressure drop of 4 kilopascals (16 in. H_2O) is capable of reducing particulate emissions to at least a level of 0.05 lb/10^6 Btu. Scrubbers do not appear capable of meeting emission standards of 0.03 lb/10^6 Btu and some reports state that they are incapable of meeting 0.05 lb/10^6 Btu. Scrubbers are most commonly used on coal-fired electric generating plants that are equipped with flue gas desulfurization systems. All units in Table 5-18 are equipped with flue gas desulfurization systems.

TABLE 5-18

Data on Particulate Scrubbing Systems Installed on Pulverized Coal-Fired Steam Generators

Source Code	Boiler Size	Sulfur	Pre-Scrubber Particulate Control	Separate Particulate Scrubber	SO_2 or SO_2 + Particulate Scrubber	Pressure Drop		Particulates[a] Scrubber Outlet		Number of Tests
		%				Kilopascals	(in. H_2O)	ng/J	(lb/10^6 Btu)	
A	125	0.5	Mechanical	None	Venturi Scrubber Carbonate	3.8	15	20-24[b]	0.046-0.055	2
B	125	0.5	Mechanical	None	Venturi Scrubber Carbonate	3.8	15	22[b]	0.051	2
C	125	0.5	Mechanical	None	Venturi Scrubber Carbonate	3.8	15	14-18[b]	0.033-0.041	3
D	350	0.7	None	None	Venturi Scrubber Lime	4.5	8	8-10	0.019-0.023	3
E	116	0.5	Mechanical	Flooded Disc Scrubber	Packed Absorber Limestone	3.0	12	16	0.037-0.038	2
F	380	2.1	Mechanical and ESP	None	Venturi	2.5	10	19-21	0.045-0.048	2
G	150	2.1	Mechanical	None	Venturi	2.5	10	9-30	0.022-0.070	10

---

a = EPA Method 5

b = EPA Sponsored Test

Ref. 5-17.

Costs

Cost Comparison Studies

Two studies, by the Electric Power Research Institute (EPRI) and PEDCo Environmental Co. for the EPA, will be used in this section to compare costs. EPRI compares electrostatic precipitators (ESPs) with baghouses (fabric filters), while PEDCo compares ESPs, baghouses and scrubbers.

ESPs and Fabric Filters - EPRI Study (5-19)

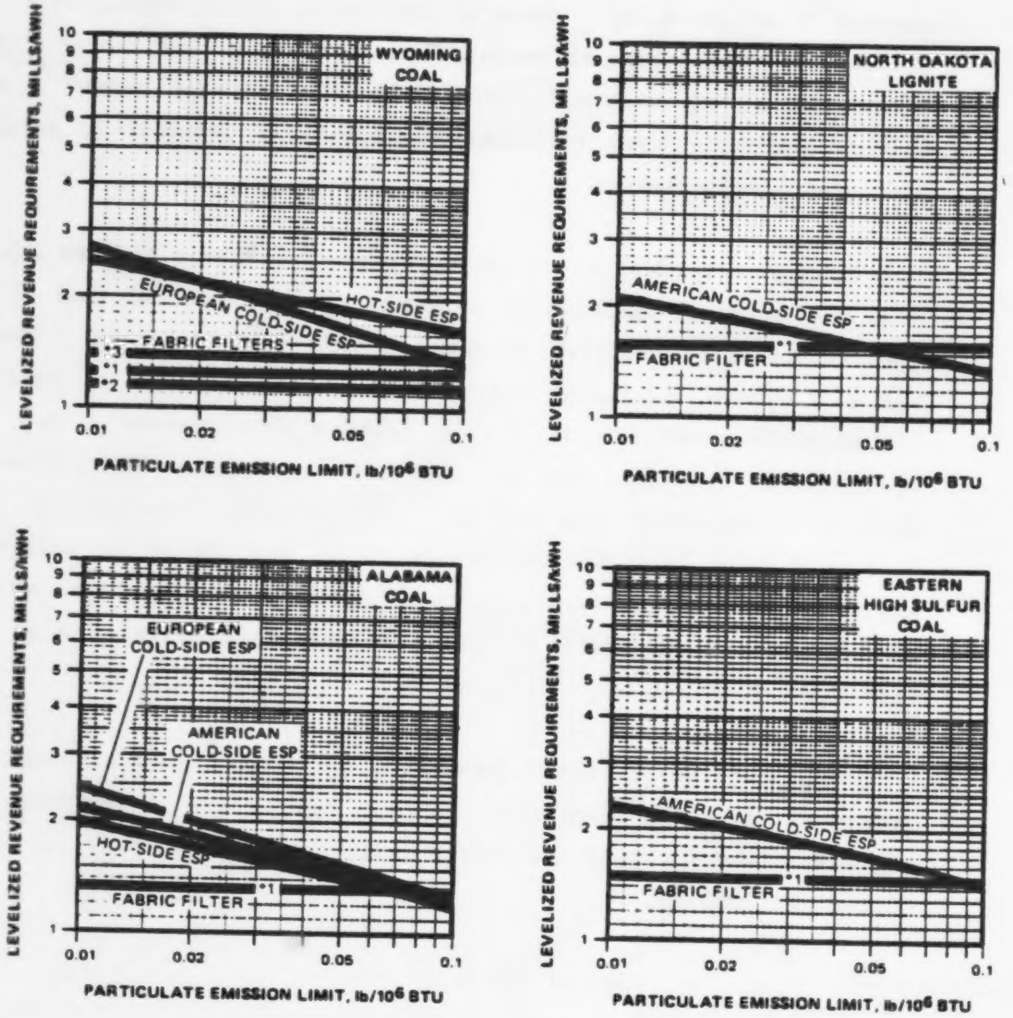
Electrostatic precipitator costs increase significantly as incremental collection efficiency requirements are increased. Baghouse (fabric filter) costs remain essentially constant due to their inherently high collection efficiency for a wide range of particle sizes. Therefore baghouse designs are specified primarily on the basis of the waste stream volume, not on desired collection efficiency. For standards that are more rigorous than the NSPS of 0.1 lb/10^6 Btu fabric filters appear to be the economic choice. However, there is little data on the long term reliability of fabric filters because they are installed in so few electric generating plants. Problems such as tolerance for highly corrosive environments and sustained high temperatures have not been fully resolved in field application.

Total Costs

A summary of the comparative economics for collection systems at a hypothetical 500 MW pulverized-coal-burning boiler is presented in Figure 5.5.* It is seen that the costs of electrostatic precipitators

---

*The levelized annual revenue requirements are defined as the present worth multiplied by the capital recovery factors used in this report. Present worth is the measure of the fixed revenue requirements to cover all project costs for the assumed life of the investment. The capital recovery factor is a ratio, 1/8.85, for 35 years at 11% minimum acceptable return.(5-19)



LEVELIZED REVENUE REQUIREMENTS FOR COLLECTION SYSTEMS

ON 500 MW (net) POWER PLANTS, BASE YEAR 1978

*1. 20-COMPARTMENT FABRIC FILTER WITH 2-YEAR BAG-REPLACEMENT
*2. 20-COMPARTMENT FABRIC FILTER WITH 4-YEAR BAG-REPLACEMENT
*3. 40-COMPARTMENT FABRIC FILTER WITH 2-YEAR BAG-REPLACEMENT

WIDTH OF LINES REFLECTS RELATIVE ACCURACY OF THE ESTIMATES

Source: Reference 5-19

DAMES & MOORE

FIGURE 5.5

increase signficantly as design limits become more restrictive to capture finer particles. Costs of the fabric filter collector do not change over the range of emission limitations. The fabric filter system has a very high efficiency uniformly and will result in compliance with the most restrictive limitations considered, assuming performance reliability.

Economic feasibility of precipitators and fabric filters depends upon the emission limitations imposed, ash and heat content of the coal, electrical qualities of the ash and bag replacement schedule. The EPRI study indicates that larger plants tend to enhance the economic favorability of fabric filters relative to ESPs. For equal outlet loadings, the fabric filter collects sub-micron matter more effectively than does the ESP. For different types of coal, (the four coal types specified in this study are defined in the section on energy use) fabric filters require no special design changes to meet the range of particulate emissions considered. Designs change only with the gas volume to be filtered.

On a percentage basis, increases in the size of the power plant increases ESP costs more than fabric filter costs. Economics that are equivalent for ESPs and fabric filters at 500 MW favor the fabric filter at 1,000 MW.

Capital Costs

EPRI developed capital estimates for each of 20 different cases, or five cases for each of the four kinds of collectors considered in the study. The categories of collectors were hot side ESP, American cold side ESP, European Cold Side ESP,* and fabric filters.

---

*American cold side ESP - located on the downstream side of the combustion air preheater. Weighted wires, maximum power density, minimum surface collection area, light mechanical rappers.

American hot side ESP - located on the upstream side of the combustion air preheater but otherwise similar to American Cold Side ESP.

European cold side - rigid frames, less power density to reduce effects of high resistivity, large surface collection area, heavy rappers.

Table 5-19 summarizes the base case estimates. It shows that for capital investment, the American cold side ESP and fabric filters are economically competitive for the base case. The tables that follow give alternatives to the base case 500 MW plant, e.g., different specific collection areas for two 500 MW plants, a 250 MW and a 1000 MW plant. Notice that economies of scale occur in all four sets of costs.

The capital investment for an ESP is a function of precipitator location in the plant, gas flow, and specific collection area. Capital investment for fabric filters is a function of factors such as gas flow, air-to-cloth ratio, and the number of compartments. Tables 5-20 through 5-23 summarize these data for the various alternatives to the base case plant. These tables show that the capital investment for hot-side ESPs and European cold-side ESPs are substantially higher than for American cold-side ESPs and fabric filters. Capital investment includes ducting, ash handling and fans.

Table 5-24 presents calculations of the capital investment costs for 500 MW alternate-case studies for the four different types of coal examined. Note the three emission limits and the corresponding changes in capital investment. For all types of ESPs an increase in emission limitations is accompanied by an increase in capital investment.

Figure 5.6 graphically presents capital investment for collection systems on 500 MW power plants in 1978 dollars. In all cases as the emission limitations become more strict, the more economically favorable fabric filters become from a capital investment viewpoint. For ESPs the capital investment increases about 20 percent each time the outlet emission limit is halved. Fabric filter efficiency is uniformly high, resulting in constant cost as the emission limits decrease.

The point at which the ESP and fabric filter lines cross in

TABLE 5-19

Capital Investment Estimate Summary For Base Case System (500 MW Plant)
Cost Units: $1000 (1978)

Design Parameter	Hot-Side ESP			American Cold-Side ESP			European Cold-Side ESP			Fabric Filter (16 comp.)		
Gas Flow Rate Collector Size[a]	2.64×10^6 acfm 400 SCA			1.9×10^6 acfm 350 SCA			1.97×10^6 acfm 550 SCA			1.97×10^6 acfm 1.812 A/C		
Cost Item	**Labor**	**Material**	**Total**	**Labor**	**Material**	**Total**	**Labor**	**Material**	**Total**	**Labor**	**Material**	**Total**
Collector & Hoppers	$1,272	$ 4,505	$ 5,777	$ 828	$2,933	$ 3,761	$1,296	$ 5,508	$ 6,804	$ 574	$4,391	$4,965
Collector Support Steel	488	970	1,458	323	640	963	497	988	1,485	317	632	949
Boiler Outlet Duct	160	409	569	150	383	533	104	268	372	149	381	530
Inlet & Outet Nozzles	356	1,362	1,718	322	1,236	1,558	360	1,386	1,746	—	--	--
ID Fan Inlet Duct	209	536	745	139	356	495	32	82	114	35	88	123
Flow Dampers	12	120	132	12	120	132	9	90	99	--	--	--
Expansion Joints	29	179	208	18	116	134	14	88	102	12	78	90
Duct Support Steel	111	222	333	94	188	282	76	152	228	28	56	84
Ash Valves	26	144	170	26	144	170	32	180	212	18	96	114
Other Ash Handling	92	320	412	133	400	533	165	551	716	99	340	439
Collector Insulation	314	399	713	151	165	316	355	385	740	668	747	1,415
Duct Insulation	356	454	810	300	327	627	245	266	511	65	70	135
Other Miscellaneous	800	800	1,600	520	520	1,040	800	800	1,600	489	870	1,359
Differential Costs	625	1,039	1,664[b]	0	0	0	0	0	0	100	400	500[c]
Indirect Field Costs	3,500	1,350	4,850	1,760	754	2,514	2,590	996	3,586	1,595	613	2,209
Total Field Costs	$8,350	$12,809	$21,159	$4,776	$8,282	$13,058	$6,575	$11,740	$18,315	$4,149	$8,762	$12,912

TABLE 5-19 (cont'd)

Capital Investment Estimate Summary For Base Case System (500 MW Plant)
Cost Units: $1000 (1978)

Design Parameter	Hot-Side ESP			American Cold-Side ESP			European Cold-Side ESP			Fabric Filter (16 comp.)		
Gas Flow Rate	2.64×10^6 acfm			1.9×10^6 acfm			1.97×10^6 acfm			1.97×10^6 acfm		
Collector Size[a]	400 SCA			350 SCA			550 SCA			1.812 A/C		
Cost Item	Labor	Material	Total	Labor	Material	Total	Labor	Material	Total	Labor	Material	Total
Total Field Costs			$21,159			$13,058			$18,315			$12,912
Additional Costs												
Engineering & Fee 3%			633			392			550			387
Contingency & Misc. 10%			2,100			1,350			1,835			1,291
Capital Investment												
Total			$23,900			$14,800			$20,700			$14,590
Relative ($/ft^2 collection area)			$22.65			$21.40			$19.20			$13.42

---

a. Collector size - SCA, specific collection area (ft^2/acfm); A/C, air-to-cloth ratio (acfm/ft^2).
b. Tempering air duct, secondary air duct, primary air duct and additional air preheater inlet and outlet duct.
c. Additional cost for larger I.D. fan and motor.

Ref. 5-19.

TABLE 5-20

Capital Investment Summaries For Alternate Cases
Hot-Side Electrostatic Precipitator

Units: $1000 (1978), Labor and Materials

Parameter	Base Case	Alternate Cases 1	2	3	4
Megawatts	500	500	500	250	1,000
SCA, ft^2/1000 acfm	400	200	800	400	400
Gas Flow, 10^6 acfm	2.64	2.64	2.64	1.32	5.28
Collector & Supports	$ 7,235	$ 3,798	$13,884	$3,697	$14,155
Ducting & Supports	3,705	3,705	3,705	1,761	6,476
Ash Handling Equipment	582	401	1,150	396	1,117
Insulation	1,523	1,165	2,230	802	2,695
Other Field Costs	8,114	5,891	12,216	3,964	16,973
Total Field	$21,159	$14,960	$33,185	$10,620	$41,416
Eng., Misc and Cont.	2,741	1,940	4,315	1,380	5,384
Capital Investment (CI)	$23,900	$16,900	$37,500	$12,000	$46,800
CI Ratio to Base	1.000	0.707	1.570	0.502	1.957
$/ft^2 Collection Area	$ 22.65	$ 32.00	$ 17.75	$ 22.75	$ 22.15

Ref. 5-19.

TABLE 5-21

Capital Investment Summaries For Alternate Cases American-Style Cold-Side Electrostatic Precipitators

Units: $1000 (1978), Labor and Materials

Parameter	Base Case	Alternate Cases			
		1	2	3	4
Megawatts	500	500	500	250	1,000
SCA, $ft^2/1000$ acfm	350	175	700	350	350
Gas Flow, 10^6 acfm	1.97	1.97	1.97	0.985	3.94
Collector & Supports	$ 4,724	$ 2,480	$ 9,066	$2,420	$ 9,242
Ducting & Supports	3,134	3,134	3,030	1,167	5,502
Ash Handling Equipment	703	473	1,286	467	1,371
Insulation	943	785	1,259	471	1,796
Other Field Costs	3,554	2,218	6,227	1,688	6,973
Total Field	$13,058	$ 9,089	$20,858	$ 6,213	$24,884
Eng., Misc and Cont.	1,742	1,211	2,472	787	3,216
Capital Investment (CI)	$14,800	$10,300	$23,600	$ 7,000	$28,100
CI Ratio to Base	1.000	0.695	1.597	0.476	1.906
$/$ft^2$ Collecting Area	$ 21.40	$ 29.80	$ 17.10	$ 20.40	$ 20.40

Ref. 5-19.

TABLE 5-22

Capital Investment Summaries For Alternate Cases
European-Style Cold-Side Electrostatic Precipitators

Units: $1000 (1978), Labor and Materials

Parameter	Base Case	Alternate Cases			
		1	2	3	4
Megawatts	500	500	500	250	1,000
SCA, ft^2/1000 acfm	550	275	1,100	550	550
Gas Flow, 10^6 acfm	1.97	1.97	1.97	0.98	3.94
Collector & Supports	$ 8,289	$ 4,364	$15,862	$4,254	$16,192
Ducting & Supports	2,661	2,661	2,661	1,612	5,858
Ash Handling Equipment	928	570	1,799	518	1,668
Insulation	1,251	881	1,990	787	2,726
Other Field Costs	5,186	2,985	3,200	2,704	10,619
Total Field	$18,315	$11,461	$31,912	$ 9,875	$37,062
Eng., Misc and Cont.	2,385	1,539	4,188	1,325	4,888
Capital Investment (CI)	$20,700	$13,000	$36,100	$11,200	$41,900
CI Ratio to Base	1.000	0.626	1.742	0.539	2.023
$/$ft^2$ Collecting Area	$ 19.20	$ 24.00	$ 16.70	$ 20.90	$ 19.40

Ref. 5-19.

TABLE 5-23

Capital Investment Summaries For Alternate Cases
Fabric Filter

Units: $1000 (1978), Labor and Materials

Parameter	Base Case	Alternate Cases 1	2	3	4
Megawatts	500	500	500	250	1,000
Air to Cloth Ratio	1.81	2.72	1.45	1.81	1.81
Gas Flow, 10^6 acfm	1.97	1.97	1.97	0.985	3.94
No. of Compartments	16	16	20	16	32
Collector & Supports	$ 5,914	$ 4,452	$ 7,219	$3,630	$11,381
Ducting & Supports	827	827	827	503	1,373
Ash Handling Equipment	553	553	667	339	1,024
Insulation	1,550	1,244	1,867	1,014	2,957
Other Field Costs	4,068	3,360	4,859	2,347	7,620
Total Field	$12,912	$10,436	$15,439	$ 7,833	$24,355
Eng., Misc and Cont.	1,678	1,356	2,007	1,018	3,166
Capital Investment (CI)	$14,590	$11,792	$17,446	$ 8,851	$27,521
CI Ratio to Base	1.000	0.808	1.196	0.606	1.886
$/ft^2 Cloth Area	$ 13.42	$ 16.26	$ 12.85	$ 16.27	$ 12.66

Ref. 5-19.

TABLE 5-24

Calculation of Capital Investment For 500 MW Case Studies

Coal	Collector Type	Emission Limit (lb/10^6 BTU)	SCA or A/C Value[a]	SCA or A/C Factor[b]	Gas Flow Value (10^6 acfm)	Gas Flow Factor[b]	Modules Value (No.)	Modules Factor[b]	Overall Cost Factor[c]	Capital Investment (\$$10^6$, 1978)[d]
Wyoming	Hot-Side ESP	0.10	368	0.95	2.68	1.01	--	--	0.97	24.9
		0.05	462	1.09	2.68	1.01	--	--	1.10	28.3
		0.014	683	1.36	2.68	1.01	--	--	1.38	35.5
	European Cold-Side ESP	0.10	536	0.98	1.86	0.95	--	--	0.93	20.7
		0.05	704	1.22	1.86	0.95	--	--	1.16	25.8
		0.014	1155	1.81	1.86	0.95	--	--	1.72	38.3
	Fabric Filter[e]	--	1.93	0.97	1.86	0.96	20	1.06	0.98	15.4
		--	1.93	0.97	1.86	0.96	20	1.06	0.98	15.4
		--	1.93	0.97	1.86	0.96	40	1.25	1.16	18.2
North Dakota Lignite	American Cold-Side ESP	0.10	326	0.96	2.41	1.21	--	--	1.16	18.4
		0.05	410	1.10	2.41	1.21	--	--	1.33	21.1
		0.014	588	1.37	2.41	1.21	--	--	1.63	26.2
	Fabric Filter	--	1.93	0.97	2.41	1.16	20	1.06	1.18	18.5
Alabama	Hot-Side ESP	0.10	263	0.78	2.43	0.92	--	--	0.72	18.5
		0.05	336	0.90	2.43	0.92	--	--	0.83	21.3
		0.014	515	1.16	2.43	0.92	--	--	1.07	27.5
	American Cold-Side ESP	0.10	473	1.20	1.97	0.91	--	--	1.09	17.3
		0.05	630	1.42	1.97	0.91	--	--	1.29	20.6
		0.014	1050	1.93	1.97	0.91	--	--	1.76	28.0

TABLE 5-24 (cont'd)

Calculation of Capital Investment For 500 MW Case Studies

Coal	Collector Type	Emission Limit	SCA or A/C		Gas Flow		Modules		Overall Cost	Capital Investment
		($lb/10^6$ BTU)	Value[a]	Factor[b]	Value (10^6 acfm)	Factor[b]	Value (No.)	Factor[b]	Factor[c]	($\$10^6$, 1978)[d]
Alabama	European	0.10	420	0.83	1.97	1.00	--	--	0.83	18.6
	Cold-Side	0.05	557	1.01	1.97	1.00	--	--	1.01	22.5
	ESP	0.014	924	1.52	1.97	1.00	--	--	1.52	33.8
	Fabric Filter	--	1.93	0.97	1.97	1.00	20	1.06	1.02	16.0
Eastern High Sulfur	American	0.10	441	1.15	2.10	0.97	—	—	1.11	17.6
	Cold-Side	0.05	567	1.34	2.10	0.97	—	—	1.29	20.5
	ESP	0.014	830	1.68	2.10	0.97	—	—	1.62	25.8
	Fabric Filter	--	1.93	0.97	2.10	1.05	20	1.06	1.07	16.8

---

a. For ESP's, SCA is the specific collection area (ft^2/acfm). For fabric filters, A/C is the air-to-cloth ratio (acfm/ft^2).

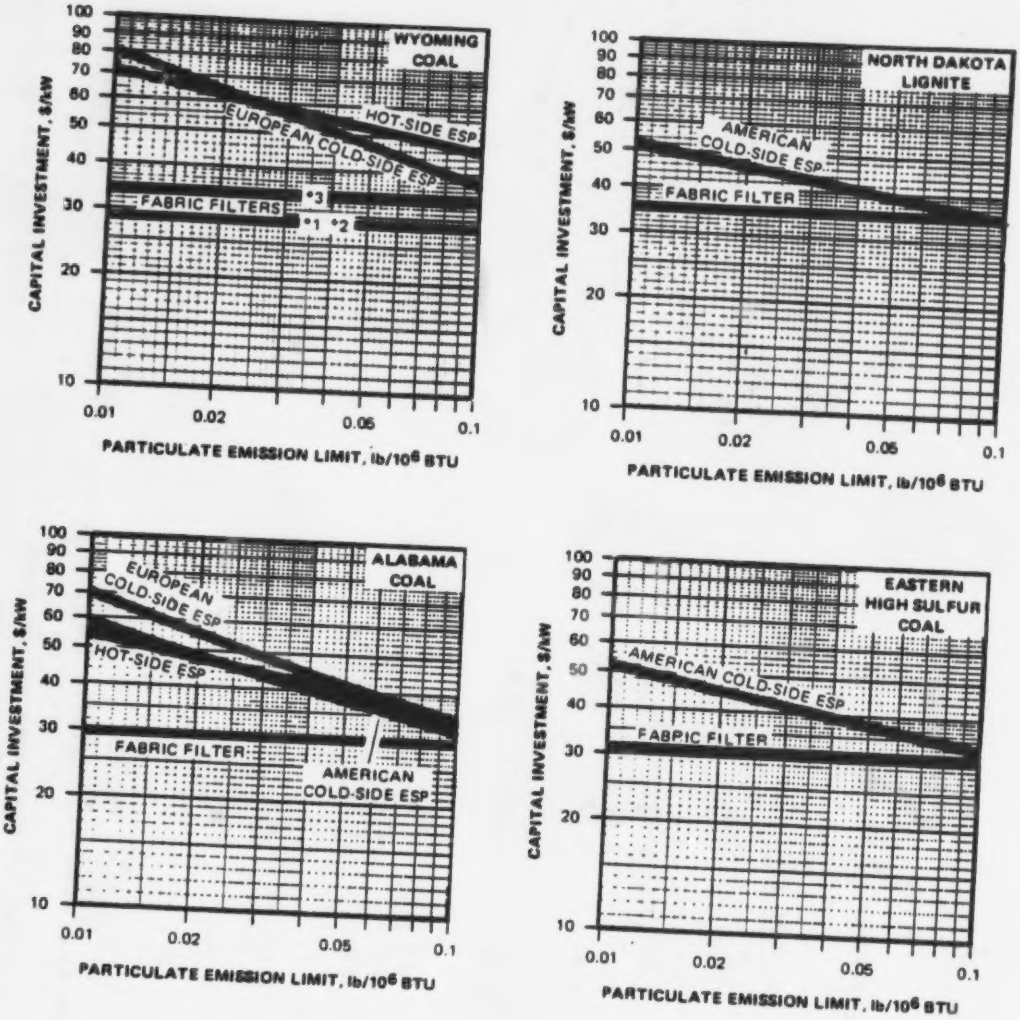
b. Factors given are ratios of specific values to base case values (see Table 5-30).

c. Overall cost factor is multiplied by base case capital investment value (Table 5-30) to obtain the specific capital investment value.

d. Results of applying a cost escalation factor to the original 1977 dollar amounts presented in the reference.

e. Three figures shown for the fabric filter applied to Wyoming coal are, from top to bottom, for a 20-compartment system and 2-year bag-replacement cycle, a 20-compartment system and 4-year bag-replacement, and a 40-compartment system and 2-year bag -replacement, respectively.

Ref. 5-19.



ESTIMATED CAPITAL INVESTMENT FOR COLLECTION SYSTEMS

ON 500 MW (net) POWER PLANTS (1978)

*1. 20-COMPARTMENT FABRIC FILTER WITH 2-YEAR BAG-REPLACEMENT.
*2. 20-COMPARTMENT FABRIC FILTER WITH 4-YEAR BAG-REPLACEMENT.
*3. 40-COMPARTMENT FABRIC FILTER WITH 2-YEAR BAG-REPLACEMENT.

WIDTH OF LINES REFLECTS RELATIVE ACCURACY OF THE ESTIMATES.

Source: Reference 5-19

FIGURE 5.6

Figure 5.6 is the point of equal capital investment, which occurs only for American Cold-Side ESPs at the highest particulate emission limit (0.1 lb/10^6 Btu). Other factors, notably the higher maintenance costs and energy costs used in creating a pressure drop across the fabric filter, must be included when considering the overall costs (levelized revenue requirements). This has been previously discussed and is summarized in Figure 5.5.

Operation and Maintenance Costs

Costs and unit factors for the maintenance of the collectors and ash-removal systems were derived for each case from estimates of the costs for the base case in the EPRI study. The base case operating costs for collector and ash removal equipment are constant at $20,000 and $60,000 per year respectively for all four types of collector systems (see Table 5-25). The significant difference in costs between the systems is that fabric filters have a higner maintenance cost than ESPs due to bag replacement, both scheduled and unscheduled. Fabric filter maintenance costs are detailed in Table 5-26.

The following assumptions were made concerning maintenance costs for fabric filters as given in the above cited EPRI study for the base case.

> Scheduled bag-replacments and costs for materials were estimated assuming a 2-year bag-replacement cycle, $40/bag, (43.0, $1978) 90 ft^2/bag, and 10% overhead.
>
> Labor for these replacements was assessed using a figure of 17 man-minutes to replace each bag at $14/man-hour (15.1, $1978).
>
> Note that these costs would be halved if a 4-year bag replacement cycle were assumed.

TABLE 5-25

Cost and Unit Factors for Operation and Maintenance for the 500 MW Base Case Systems

Collector System	Collector Equipment						Ash Removal Equipment					
	Operation ($/yr)		Maintenance ($/year/$10^6$ft^2)				Operation ($/yr)		Maintenance ($/year/$10^6$ft^2)			
			Material		Labor				Material		Labor	
	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978
Hot-Side ESP	20,000	21,520	25,000	26,900	25,000	26,900	60,000	64,560	30,000	32,280	30,000	32,280
American Cold-Side ESP	20,000	21,520	25,000	26,900	25,000	26,900	60,000	64,650	10,000	10,760	10,000	10.760
European Cold-Side ESP	20,000	21,520	15,000	16,140	15,000	16,140	60,000	64,560	10,000	10,760	10,000	10,760
Fabric Filter	20,000	21,520	280,000[a]	301,280	35,000	37,600	60,000	64,560	8,000[a]	8,608	8,000[b]	8,608

---

a. This figure, estimated for two-year bag-replacement cycles, is approximately halved for four-year bag-replacement cycles.

b. These figures increase to $15,000/yr/$10^6$ft^2 for the 40-compartment system.

Ref. 5-19.

TABLE 5-26

Details of Base Case Fabric Filter Collector Maintenance Costs

Type of Maintenance	Maintenance Costs ($\$/yr/10^6$ ft^2)					
	Materials		Labor		Total	
	1977	1978	1977	1978	1977	1978
Scheduled bag-replacement*	250,000	269,000	20,000	21,520	270,000	290,520
Unscheduled bag-replacement	25,000	26,900	10,000	10,760	35,000	37,660
Additional Maintenance	5,000	5,380	5,000	5,380	10,000	10,760
Total	280,000	301,280	35,000	37,660	315,000	338,940

---

*Costs presented are for a two-year bag replacement cycle. If a four-year bag replacement cycle is assumed, costs decrease approximately 50%.

Ref. 5-19.

> Under the second item, in Table 5-26 (unscheduled bag-replacements), costs were estimated by assuming that 5% of the inventory requires replacement each year, for material costs, the same figures as mentioned above were used except 1 man-hour/bag was assumed.
>
> Costs for additional maintenance were determined using the figure of 350 hours/year for maintenance labor involving controls, dampers, fans, and other components.
>
> For this last category (additional maintenance) it was assumed that the cost of materials is the same as for labor. The totals in Table 5-26 are about half of those shown when it is assumed that the length of time between bag replacements is doubled. The totals would be insignificantly higher for a 40-compartment system."(5-18)

Table 5-27 summarizes all operation and maintenance costs for the base case by type of coal. Total operation and maintenance costs per year are consistently higher for fabric filters than for the ESPs.

TABLE 5-27

Summary of Annual Operation and Maintenance Costs for Case Studies[a]

Coal	Collector Type	Emission Limit (lb/10^6 BTU)	Collection Area (10^6 ft^2)	Collection System Cost Operation	Collection System Cost Maintenance Material	Collection System Cost Maintenance Labor	Ash Removal System Cost Operation	Ash Removal System Cost Maintenance Material	Ash Removal System Cost Maintenance Labor	Total Cost Operation and Maintenance
Wyoming	Hot-Side ESP	0.10	0.985	$21,500	$26,900	$26,900	$64,600	$32,300	$32,300	$204,400
		0.05	1.239	21,500	33,400	33,400	64,600	39,800	39,800	232,400
		0.014	1.830	21,500	48,400	48,400	64,600	59,200	59,200	408,900
	European Cold-Side ESP	0.10	0.966	21,500	16,100	16,100	64,600	10,800	10,800	139,900
		0.05	1.309	21,500	21,500	21,500	64,600	14,000	14,000	156,000
		0.014	2.148	21,500	34,400	34,400	64,600	22,600	22,600	200,100
	Fabric Filter[b]	—	0.964	21,500	290,500	36,600	64,600	8,200	8,200	430,400
				21,500	145,300	18,300	64,600	8,200	8,200	266,800
				21,500	290,500	36,600	64,600	15,100	15,100	443,300
North Dakota Lignite	American Cold-Side ESP	0.10	0.785	21,500	21,500	21,500	64,600	8,500	8,500	146,300
		0.05	0.987	21,500	26,900	26,900	64,600	10,800	10,800	161,400
		0.014	1.418	21,500	37,700	37,700	64,600	15,100	15,100	191,500
	Fabric Filter	—	1.249	21,500	376,600	47,300	64,600	10,800	10,800	530,500
Alabama	Hot-Side ESP	0.10	0.645	21,500	17,200	17,200	64,600	20,400	20,400	161,400
		0.05	0.824	21,500	22,600	22,600	64,600	26,900	26,900	185,100
		0.014	1.263	21,500	34,400	34,400	64,600	40,900	40,900	236,700
	American Cold-Side ESP	0.10	0.928	21,500	34,400	34,400	64,600	9,700	9,700	174,300
		0.05	1.238	21,500	46,300	46,300	64,600	12,900	12,900	204,400
		0.014	2.063	21,500	77,500	77,500	64,600	22,600	22,600	286,200

TABLE 5-27 (cont'd)

Summary of Annual Operation and Maintenance Costs for Case Studies[a]

Coal	Collector Type	Emission Limit (lb/10^6 BTU)	Collection Area (10^6 ft^2)	Collection System Cost Operation	Collection System Cost Maintenance Material	Collection System Cost Maintenance Labor	Ash Removal System Cost Operation	Ash Removal System Cost Maintenance Material	Ash Removal System Cost Maintenance Labor	Total Cost Operation and Maintenance
Alabama	European Cold-Side ESP	0.10	0.825	$21,500	$12,900	$12,900	$64,600	$ 8,900	$ 8,900	$130,200
		0.05	1.094	21,500	17,200	17,200	64,600	11,800	11,800	144,200
		0.014	1.816	21,500	29,100	29,100	64,600	19,400	19,400	182,900
	Fabric Filter[b]	--	1.021	21,500	307,700	38,700	64,600	8,800	8,800	449,800
Eastern High-Sulfur	American Cold-Side ESP	0.10	0.927	21,500	34,400	34,400	64,600	10,000	10,000	174,300
		0.05	1.191	21,500	45,200	45,200	64,600	12,900	12,900	202,300
		0.014	1.743	21,500	65,600	65,600	64,600	18,300	18,300	253,900
	Fabric Filter	--	1.088	21,500	328,200	40,900	64,600	9,400	9,400	473,400

---

a. All cost figures are in 1978 dollars, obtained by applying a cost escalation factor to the original 1977 dollar amounts presented in this reference.

b. Entries for Wyoming coal applied to the fabric filter represent three alternatives--from top to bottom, the 20-compartment system with a 2-year bag replacement cycle, the 20-compartment system with a 4-year bag-replacement cycle, and the 40-compartment system with a 2-year bag-replacement cycle.

Ref. 5-19.

ESPs, Fabric Filters and Scrubbers - Pedco Study(5-21)

PEDCo Environmental, Inc. developed cost estimates for electrostatic precipitators, fabric filters and scrubbers with cost differentials for boilers designed for western subbituminous coals versus eastern coals as well as other parameters. The study considered particulate emissions of 0.05 lb/10^6 Btu (22 ng/J) and 0.03 lb/10^6 Btu (13 ng/J). These are the proposed standards for particulate emissions from fossil fueled power plants. (NSPS, 40 CFR 60.43) Only ESPs and fabric filters can consistently attain those levels. Wet venturi scrubbers were examined for the present NSPS level of 0.1 lb/10^6 Btu (43 ng/J) and the proposed 0.05 lb/10^6 Btu (22 ng/J) particulate emission levels.

Costs considered were; 1) capital costs which include equipment, materials, installation and, 2) annual costs which are operation and maintenance costs and include raw materials, utilities, and labor for maintenance.

The cost system is based upon a typical new coal-fired plant model. Six different ranks and grades of coal from various locations were examined. Table 5-28 presents a summary of the model plant that PEDCo developed with assumptions used in the cost analysis of particulate control devices. Table 5-29 presents an analysis of the coal used in the study. Table 5-30 lists parameters for the particulate control systems cost estimates. Cost estimates are expressed in mid-1980 dollars with an escalation rate of 7.5 percent per year and 1976 as the base year. Table 5-31 lists costs of particulate control alternatives.

For a 500 MW plant meeting 13.0 ng/j (0.03 lb/10^6 Btu) standards with 3.5% sulfur and 14% ash, PEDCo estimates capital costs for fabric filters to be $51.83/kw with annual costs for operating and maintenance at 0.29 mills/kwh and fixed costs at 1.43 mills/kwh.

TABLE 5-28

Model Plant Parameters and Assumptions Used In The Particulate Control Analysis[a]

Model Plant Parameters	Characteristics and Assumptions				
Plant capacities, MW	25, 100, 200, 500, and 1000 (single boilers)				
Plant status	New				
Coal characteristics	(see Table 5-33)				
Particulate control requirements	(1) The existing NSPS of 43 ng particulate/joule heat input (0.1 lb/10^6 Btu) (2) 22 ng particulate/joule heat input (0.05 lb/10^6 Btu) (3) 83 ng particulate/joule heat input (0.03 lb/10^6 Btu)				
Location	Midwest location - East North Central Region				
Boiler data					
Plant capacity - MW	25	100	200	500	1000
Heat rate[b] - 10^3 joules/kwh (Btu/kwh)	10,540 (10,000)	10,013 (9,500)	9,700 (9,200)	9,490 (9,000)	9,170 (8,200)
Flue gas flow rate[b] - m^3/sec/MW (acfm/MW)	1.65 (3,500)	1.58 (3,350)	1.50 (3,175)	1.45 (3,080)	1.42 (3,000)
Flue gas temperature-°C (°F)	155 (310)	155 (310)	155 (310)	155 (310)	155 (310)
Remaining life-years	35	35	35	35	35
Capacity Factors	0.65	0.65	0.65	0.65	0.65

---

a. Ref. 5-21.

b. Detailed Cost Estimate for Advanced Effluent Desulfurization Processes, prepared for Control Systems Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, under Interagency Agreement EPA IAG-134(d) Part A, by G.C. McGlamery, et al., Tennessee Valley Authority, pp. 60, 66. May, 1974.

TABLE 5-29

Analyses of Coals Used As The Cost Estimating Basis

Coal Type	Total Sulfur %	Pyritic Sulfur %	Ash %	Heating Value J/g (Btu/lb)
Eastern bituminous	6.39	4.6	14	28,000 (12,000)
Eastern bituminous	3.48	2.49	14	28,000 (12,000)
Western subbituminous	0.8	—	8	23,000 (10,000)
Western lignite	0.4	--	6	19,000 (8,000)
Anthracite	0.8	—	6	31,000 (13,500)

Ref. 5-21.

TABLE 5-30

Particulate Emission Control Device Design Parameters[a]

Control System	Design Parameter	Parameter Units	Regulation Level - ng/J		
			43	22	13
Cold-Side ESP	SCA[b]	$m^2/m^3/sec$ ($ft^2/1000$ acfm)	47 (240)	59 (300)	71 (360)
	Temperature	°C (°F)	154 (310)	154 (310)	154 (310)
Hot-Side ESP	SCA[b]	$m^2/m^3/sec$ ($ft^2/1000$ acfm)	79 (400)	108 (550)	128 (650)
	Temperature	°C (°F)	371 (700)	371 (700)	371 (700)
Fabric Filter	A/C[c]	$m^3/sec/m^2$ ($acfm/ft^2$)			0.01:1 (2:1)
Venturi Scrubber	L/G[d]	$1/m^3$ (gal/1000 acfm)	2 (15)	2 (15)	
	Gas Velocity	m/sec (ft/sec)	38 (125)	38 (125)	
	Pressure Drop	mm H_2O (inches H_2O)	203 (8)	762 (30)	

---

a. Ref. 5-21.
b. SCA - Specific collection area.
c. A/C - air-to-cloth ratio.
d. L/G - liquid-to-gas ratio.

TABLE 5-31

Costs of Particulate Control Alternatives

Regulation Level	Coal Contents		Boiler Capacity	Capital Cost - $/kw			Annual Cost - mills/kwh					
	Sulfur	Ash					O & M[b]			Fixed[c]		
ng/J	%	%	MW	FF[d]	ESP	VS[e]	FF[d]	ESP	VS[e]	FF[d]	ESP	VS[e]
13.0	0.8	8.0	25		182.20			3.27			5.44	
			100		98.22			1.72			2.93	
			200	69.47			0.37			1.93		
			500	58.45	80.71		0.34	1.36		1.62	2.41	
			1000	53.56	73.37		0.33	1.24		1.48	2.19	
	3.5	14.0	25		91.00			1.84			2.72	
			100		57.32			0.98			1.71	
			200	59.89			0.32			1.65		
			500	51.83	31.82		0.29	0.54		1.43	0.95	
			1000	46.73	28.96		0.28	0.48		1.30	0.87	
22.0	0.8	8.0	25		171.40	177.08		3.07	1.41		5.12	6.98
			100		90.67	129.47		1.58	1.29		2.71	5.10
			500		68.45	72.84		1.17	0.79		2.04	2.98
			1000		65.13	58.72		1.10	0.59		1.94	2.27
	3.5	14.0	25		89.80	178.48		1.81	1.45		2.68	7.15
			100		53.16	128.10		0.91	1.30		1.59	5.15
			500		28.21	72.63		0.47	0.80		0.84	3.03
			1000		24.76	68.65		0.41	0.78		0.74	2.87
43.0	0.8	8.0	25		134.60	111.64		2.49	1.38		4.02	4.40
			100		76.06	101.04		1.32	1.25		2.27	3.98
			500		52.53	58.93		0.89	0.76		1.57	2.41
			1000		50.15	46.07		0.84	0.56		1.50	1.78

TABLE 5-31 (cont'd)

Costs of Particulate Control Alternatives

Regulation Level	Coal Contents		Boiler Capacity	Capital Cost - $/kw			Annual Cost - mills/kwh					
	Sulfur	Ash					O & M[b]			Fixed[c]		
ng/J	%	%	MW	FF[d]	ESP	VS[e]	FF[d]	ESP	VS[e]	FF[d]	ESP	VS[e]
43.0	3.5	14.0	25		91.80	122.52		1.82	1.42		2.74	4.51
			100		51.11	99.97		0.87	1.26		1.53	4.02
			500		26.85	58.67		0.45	0.77		0.80	2.45
			1000		23.61	57.21		0.39	0.75		0.71	2.39

---

a. Ref. 5-21. FF - fabric filters, ESP - electrostatic precipitators, VS - venturi scrubber. Costs are in August, 1980 dollars, as given in the reference.

b. O&M - operation and maintenance.

c. Fixed - depreciation, taxes, insurance, and cost of capital (interest).

d. Level examined was 13.4 ng/J.

e. Costs are for venturis as an integral part of a flue gas desulfurization system.

Capital costs for ESPs are lower at $31.82/kw with annual costs for operation and maintenance at 0.54 mills/kwh and fixed costs of 0.95 mills/kwh. Capital costs for ESPs and scrubbers progressively increase as regulation levels decrease, while fabric filter costs remain constant. Relative costs for all systems tend to decrease as MW capacity increases.

Capital costs would increase about 5 percent for a cold side ESP on a 500 MW unit burning eastern high sulfur coal if the standards were changed from 0.1 lb/10^6 Btu to 0.05 lb/10^6 Btu. Capital costs for a hot-side ESP would increase about 30 percent for western low sulfur coal in a 500 MW unit. At 0.05 lb/10^6 Btu standards, fabric filters become more economical for low sulfur coal than hot-side ESPs in that capital costs become 28 percent less and annual costs 48% less.

The last Table 5-32 gives capital investment and annual operating costs for fabric filters for a 500 MW unit. It can be seen that maintenance and bag replacement represent substantial costs on an annual basis.

Summary

The EPRI study concluded the following:

As stricter emission limitations are utilized, the capital and annual costs for ESPs increase. At 0.1 lb/10^6 Btu, fabric filters are slightly less expensive than ESPs. At 0.03 lb/10^6 Btu, ESP capital and annual costs are approximately 50% greater than costs for fabric filters, whose costs are uniform for particulate emission limitations.

Economics that are equivalent for ESPs and fabric filters at 500 MW favor the fabric filter at 1,000 MW.

TABLE 5-32

Capital Investment and Annual Operating Costs Fabric Filters[a]

	Item	Cost (1978$)[b]
1) CAPITAL INVESTMENT	Direct Costs	
	Fabric Filters	$11,718,315
	Ash Handling	2,254,383
	Ducting	701,220
	Subtotal	14,673,918
	Indirect Costs (33.75% of direct costs)	4,952,464
	Contingency (20% of direct & indirect costs)	3,925,286
	Total capital Investment	$23,550,668
	($/kw)	47.11
2) ANNUAL OPERATING COSTS	Utilities	
	Electricity	242,332
	Water	17,880
	Subtotal	260,212
	Operating & maintenance[c]	663,308
	Overhead & administration	132,039
	Fixed cost (15.58% of total capital costs)	5,358,016
	Total Annual Costs	6,413,573

---

a. Estimates are for a 500 MW plant burning 0.8% sulfur coal at a particulate emissions limit of 13.4 ng/J.

b. Results of applying a cost escalation factor to the 1977 dollar amounts given in the reference.

c. Includes all material and manpower required to operate, monitor, control, maintain and repair the system. Replacement bags are included in this figure.

Ref. 5-19.

For a base case of 500 MW, capital investment is less for fabric filters, with the American style cold side ESP being only slightly less in capital investment cost.

Operation and maintenance costs for fabric filters are much higher than for the ESPs. This expense comes from bag replacement schedules and is many times higher than the highest ESP operation and maintenance costs. Even if bag life is expanded from 2 to 4 years, material costs would only be reduced to approximately six times higher than the most expensively maintained ESP.

The PEDCo study found that:

For ESPs and scrubbers, capital and annual costs increase as the demands of regulation increase. All devices tend to show economics of scale as a plant becomes larger (1000 MW). In general, capital costs of fabric filters are lower than for ESPs or scrubbers, but operating and maintenance costs are higher. At emission levels of 0.05 $lb/10^6$ Btu, fabric filters become more econmical than ESPs.

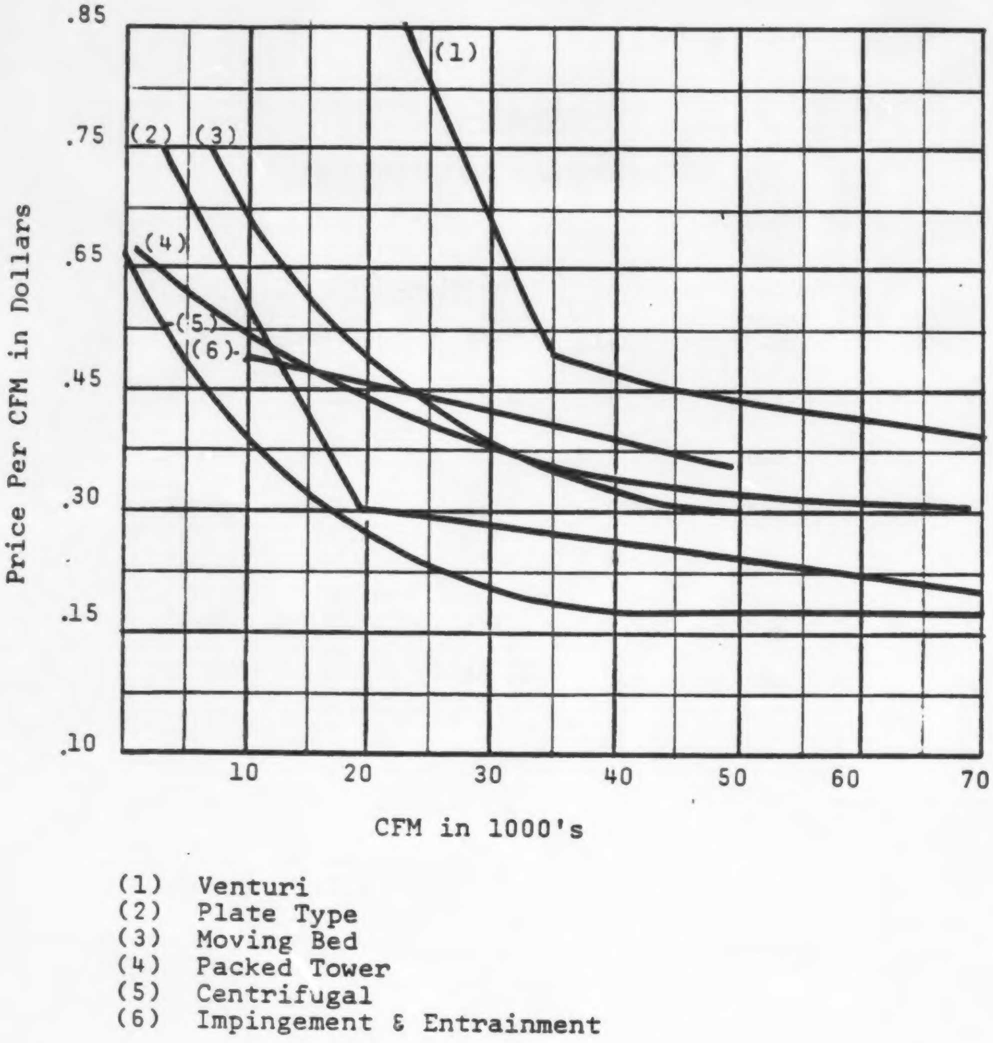
Scrubber Costs

As with the costs involved in other air pollution control devices, scrubber prices depend upon a number of variables. These include: gas flow rate (which varies with each scrubber type), type of construction, thickness of material, and special design requirements.

Price per cfm is but one measure of the costs of scrubbers. Figure 5.7 compares various scrubber types based on price per cfm. The venturi scrubber is considerably more expensive than most others because of the costs incurred in obtaining high efficiency through the throat, elbow and cyclone mechanisms.

Several electric generating plants utilizing scrubbers were surveyed by the Southern Research Institute in 1973.(5-18) They observed a 360 MW plant whose approximate installed cost for a scrubber system was $8 million, or about $22/KW. Operating labor costs were for one man per shift while maintenance labor costs were for three to five men on three eight-hour shifts. Another plant had three scrubbers on three units that produced 575 MW. The total installed cost of all three scrubber units was $30 million, or $52/KW. Total labor and maintenance costs, not including materials, was approximately $500,000/yr. These and other plants quoted the prices persented in Table 5-33. The lack of consistency in those figures (i.e., costs vs. MW output) reflects the different kinds of scrubbers installed and the specific requirements of each different electric generating plant.

Venturi scrubbers are the most common type of scrubber utilized for removing particulates from flue gases of coal-fired power plants. At the emission standard of 43.0 ng/J (0.1 $lb/10^6$ Btu), venturi scrubbers have lower capital and annual costs than ESPs for low sulfur, low ash content coal. For high sulfur (3.5%) and high ash (14.0%) content, capital and annual costs for ESPs become less. As



SCRUBBER PRICES
CARBON STEEL 3/4" PLATE

Source: Reference 5-22

DAMES & MOORE

FIGURE 5.7

TABLE 5-33

Wet Scrubbers - Installed Cost

Power Plant Output MW	Installed Cost $ (millions) 1973	 1978	 $/kw 1973	 1978
100	3.2	4.69	32	46.94
100	4.0	5.87	40.0	58.68
165	3.9	5.72	23.6	34.62
350	10.4	15.26	29.7	43.57
360	8	11.74	22	32.27
575	30	44.01	52	76.28

Ref. 5-18.

the emission limitations decrease to 22 ng/J (0.05 $lb/10^6$ Btu), venturi scrubbers compete well with ESPs for low sulfur and low ash content coals. Venturi scrubbers, however, almost double in capital costs when high sulfur/ash is burned.

In summary, scrubbers can compete economically with other control devices under favorable conditions for the present standards. They do not appear to be able to compete economically for the proposed standards of 13.0 ng/J (0.03 $lb/10^6$ Btu).

Energy Use

The Electric Power Research Institute (EPRI) has estimated the power requirements of particulate collection systems for a hypothetical 500 MW pulverized-coal-fired boiler.(5-19) The two collection systems studied were electrostatic precipitators and fabric filters. Wet scrubbers were not considered because of their relatively low efficiencies for collection of fine (sub-2 micron) particulates.

The variability in coal combustion characteristics resulted in the selection of four different coal types for the purpose of comparing collector systems under conditions requiring different collector system designs. These coals are identified by region or state of origin for convenience only, since they are not necessarily representative of the coal found in that state or region. General descriptions of these coals follow, as presented in the EPRI report.

- Wyoming Coal - Typical of low-sulfur coal from the Hanna region in southeastern Wyoming, this coal is a medium-volatile sub-bituminous coal which produces fly ash having a high resistivity.

- North Dakota Lignite - The analysis is typical of those coals found in western North Dakota, eastern Montana, and northern South Dakota. The quantity of ash, the moisture and the sodium content are relatively high, and the resistivity of the ash is low.

- Alabama - This coal is similar to those mined in the Warrior River fields in north-central Alabama. The coal is low-volatile bituminous and has an erratic ash content. The resistivity is right at the point above which American-style cold-side ESPs may no longer be suitable.

- Eastern High-Sulfur - The analysis shown is typical for high-volatile bituminous coals available by barge along the Ohio River. The ash content is erratic, but the resistivity is low due to the high sulfur content.

Power requirements of the collection systems are presented in Table 5-34 by type of coal burned. The ESPs presented were selected based on coal type, since only certain types of ESPs are suitable for a particular coal type.* Other parameters pertinent to power consumption are also presented in the table (e.g., gas flow-rate). Results show the basic superiority of fabric filter systems in terms of power consumption, especially as the particulate emission limits become more stringent.

Table 5-35 presents the energy consumption of various particulate emission control systems at three levels of emissions for a 1000 megawatt power plant. The fabric filter is the most energy efficient particulate control system. Most of the energy consumed by fabric filters and scrubbers is used to overcome pressure drop. Most of the energy consumed by an ESP system is used to produce an electrical field. A high efficiency fabric filter operating at 1.25 kilopascals (5.0 in. H_2O) pressure drop uses about 0.4 percent of the power output of a coal-fired plant. A high efficiency scrubber operating at 3.75 kilopascals (15 in. H_2O) pressure drop consumes about 1.2 percent, or three times as much power as a fabric filter. Total annual particulate emissions resulting from control at three different levels are also presented in the table.

Table 5-36 presents energy penalties associated with particulate control alternatives either as percentage of gross power output or in mills per kilowatt hour. It can be seen from this table that as the

* See cost comparison section for a brief description of the three ESP types, and a discussion of the EPRI case studies.

TABLE 5-34

Power Requirements for Particulate Collection Systems - EPRI Case Studies[a]

Coal	Collector Type	Emission Limit (lb/10^6 BTU)	Collection Area (10^6 ft^2)	Gas Flow-Rate (10^6 acfm)	Connected Power (kw)	Maximum Demand (kw)	Power Consumption (10^6kwh/yr)
Wyoming	Hot-Side ESP	0.10	0.985	2.68	5900	3800	26
		0.05	1.239	2.68	7300	4500	31
		0.014	1.830	2.68	9900	5800	41
	European Cold-Side ESP	0.10	0.966	1.86	4500	3300	20
		0.05	1.309	1.86	6300	4200	26
		0.014	2.148	1.86	9600	6300	38
	Fabric Filter[b]	--	0.964	1.86	4800	3500	17
					4400	3200	17
North Dakota Lignite	American Cold-Side ESP	0.10	0.785	2.41	6200	4100	26
		0.05	0.987	2.41	7300	4800	30
		0.014	1.418	2.41	10000	6400	41
	Fabric Filter	—	1.249	2.41	5800	4100	21
Alabama	Hot-Side ESP	0.10	0.645	2.43	4200	2800	19
		0.05	0.842	2.43	5200	3400	23
		0.014	1.263	2.43	7200	4400	31
	American Cold-Side ESP	0.10	0.928	1.97	4300	3200	18
		0.05	1.238	1.97	5500	4000	23
		0.014	2.063	1.97	8600	5900	34
	European Cold-Side	0.10	0.825	1.97	4800	3400	21
		0.05	1.094	1.97	5800	4000	25

TABLE 5-34 (cont'd)

Power Requirements for Particulate Collection Systems - EPRI Case Studies[a]

Coal	Collector Type	Emission Limit ($lb/10^6$ BTU)	Collection Area (10^6 ft^2)	Gas Flow-Rate (10^6 acfm)	Connected Power (kw)	Maximum Demand (kw)	Power Consumption (10^6kwh/yr)
Alabama	Fabric Filter	--	1.021	1.97	5000	3600	18
Eastern High-Sulfur	American Cold-Side ESP	0.10	0.927	2.10	6200	4100	26
		0.05	1.191	2.10	7800	5100	32
		0.014	1.743	2.10	10000	6700	42
	Fabric Filter	—	1.088	2.10	5200	3700	18

---

a. Ref. 5-19.

b. Upper figures are for a 20 compartment system and the lower figures are for a 40 compartment system.

TABLE 5-35

Estimated Power Consumption and Pollution From Particulate Control at 1000 Megawatt Power Plant[a]

Parameter	Control Device	Particulate Emission Control Level - ng/J		
A. Power Consumption - Megawatts	Scrubber	—	12[c]	8[d]
	ESP	9	8	6
	Baghouse	4[e]	f	f
B. Particulate Air Emissions[b] - Metric tonnes/yr (Tons/yr)	Scrubber	--	15.5 (17.1)	20.7 (22.8)
	ESP	7.0 (7.7)	10.3 (11.4)	15.5 (17.1)
	Baghouse	3.1 (3.4)	f	f

---

a. From reference 5-17.

b. Assumes 0.34 joules heat input per joule electrical output (10,000 Btu/kw hr) and 5694 operating hours per year.

c. 3.75 kilopascals (15 in. H_2O) pressure drop.

d. 2.5 kilopascals (10 in. H_2O) pressure drop.

e. 1.25 kilopascals (5 in. H_2O) pressure drop.

f. Baghouses are sized to the waste stream volume, not to a desired control level. These values would therefore be equal to those at the strictest control level.

Ref. 5-16.

TABLE 5-36

Energy Penalties[a] Associated With Particulate Control Alternatives

Regulation Level	Sulfur %	Ash %	Boiler Capacity Megawatts	Energy Penalty: Fabric Filters[b] mills/kwh	Fabric Filters[b] %	Electrostatic Precipitators mills/kwh	Electrostatic Precipitators %	Venturi Scrubbers[c] mills/kwh	Venturi Scrubbers[c] %
13.0 ng/j	0.8	8.0	25			0.32	1.25		
			100			0.28	1.14		
			200	0.08	0.33	0.27	1.10		
			500	0.08	0.32	0.26	1.04		
			1000	0.08	0.31	0.25	1.01		
	3.5	14.0	25			0.09	0.35		
			100			0.09	0.35		
			200	0.07	0.27	0.08	0.34		
			500	0.07	0.26	0.08	0.33		
			1000	0.06	0.26	0.08	0.32		
22.0 ng/j	0.8	8.0	25			0.27	1.10	0.60	2.39
			100			0.25	1.00	0.57	2.38
			500			0.23	0.93	0.53	2.10
			1000			0.23	0.90	0.51	2.04
	3.5	14.0	25			0.08	0.32	0.50	1.99
			100			0.07	0.28	0.48	1.90
			500			0.06	0.26	0.44	1.75
			1000			0.06	0.25	0.43	1.70
43.0 ng/j	0.8	8.0	25			0.18	0.72	0.15	0.58
			100			0.18	0.72	0.14	0.55
			500			0.17	0.67	0.12	0.50
			1000			0.16	0.65	0.12	0.49
	3.5	14.0	25			0.06	0.24	0.12	0.48
			100			0.06	0.24	0.12	0.46
			500			0.06	0.23	0.11	0.42
			1000			0.06	0.22	0.10	0.41

---

a. Energy penalties expressed in operating costs in mills per kilowatt hour of plant power output, and as a percent of the plant's power output required for device operation.

b. Level examined was 13.4 ng/j.

c. Costs are for venturis as an integral part of a flue gas desulfurization system.

size of electric generating plants increases, energy costs for control devices (per unit of plant generating capacity) tend to stay the same or go down, regardless of the level of emission limitations. Fabric filters appear to require the least amount of energy on all size plants for all kinds of coals.

Residuals

Coal is burned at temperatures up to 1700°C in the production of electricity. The inorganic solid residue remaining after combustion is the ash. The quantity of ash produced can range from 3 to 30 percent of the total weight of coal burned, with 7 to 15 per cent being representative.(5-23)

Residuals are classified as either fly ash, composed of finer particles that are entrained in the flue gas stream, or bottom ash, composed of coarser, heavier particles that accumulate in the bottom of the boiler as dry ash or viscous slag. Whether ash becomes fly ash or bottom ash depends on the boiler type, the kind of boiler bottom, and the kind of coal burned.

The first factor, boiler type, is possibly the most important in determining ash distribution between fly ash and bottom ash. Stoker fuel units emit the smallest proportion of fly ash, and it is relatively coarse. In cyclone units, the melting point for the ash is exceeded and therefore 80-85 percent of the ash is melted and collected as slag.(5-23) The ash produced by pulverized coal units is usually distributed as 65-80 percent fly ash and the remainder as bottom ash.(5-23)

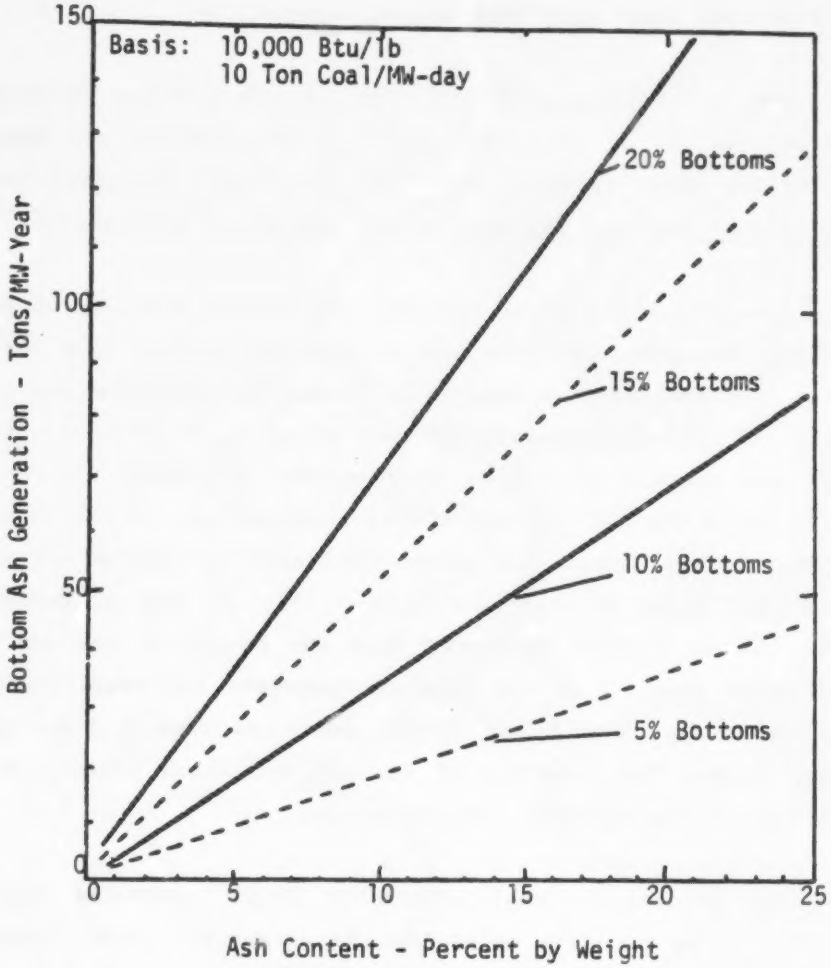
The type of boiler bottom also has an effect on the distribution of ashes. Wet bottom boilers are designed to produce and process a much larger proportion of bottom ash than dry bottom boilers. Wet bottom boilers are better utilized with coal containing ash with low fusion temperatures, whereas the reverse is true for dry bottom boilers. Ash fusion temperature signifies the temperature at which the mineral matter will melt. Ashes with low fusion temperatures tend to melt within the boiler leaving a higher percentage of bottom ash residue than ashes with high fusion temperatures.

The quantity and description of ash further depends on the characteristics of the coal. Coal characteristics are dependent on geological factors, which have been previously discussed (see Radionuclides in Coal and Its Combustion Products in this section).

As a result of these factors, the actual quantity of bottom ash and fly ash generated from coal combustion varies. One author estimates that the relative amounts of bottom ash generated can range from 10 to 175 tons per megawatt per year on a dry solids basis, based on a coal ash content of 5.0 to 25.0 percent by weight, a coal heating value of 10,000 BTU/lb, and a coal consumption rate of 10 tons coal/MW-day.(5-23) Figure 5.8 shows the range of bottom ash generation from coal fired boilers producing 5, 10, 15, and 20 percent bottom ash. It is further estimated that the amount of fly ash collected can range from 80 to 450 tons per megawatt per year.(5-23) Figure 5.9 shows the quantity of flyash generated from a model coal-fired power plant. The quantity of fly ash collected depends on the efficiency of the emission control device.

The Argonne National Laboratory (5-23) estimated the ash production rates for five model 1000 MW coal-fired power plants. These estimates are presented in Table 5-37 for a cyclone furnace producing 75 percent bottom ash and 25 percent fly ash, and a dry-bottom pulverized-coal boiler producing 20 percent bottom ash and 80 percent flyash. The data assumes a 70 percent capacity factor for each plant.

Fly ash and bottom ash are usually sluiced or piped as a slurry

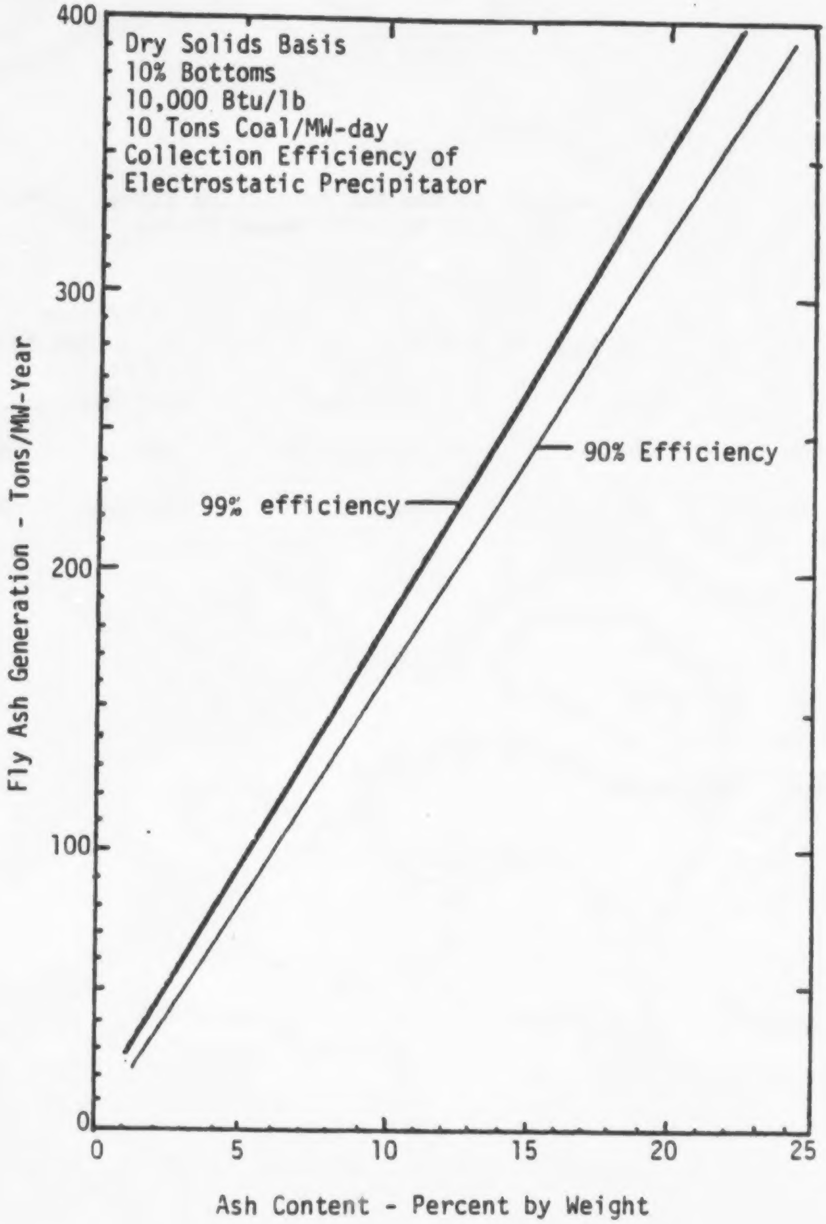


BOTTOM ASH GENERATION
FOR COAL-FIRED BOILERS

Source: Reference 5-23

DAMES & MOORE

FIGURE 5.8



FLY ASH GENERATION

FOR COAL-FIRED BOILERS

Source: Reference 5-23

DAMES & MOORE

FIGURE 5.9

TABLE 5-37

Fly Ash and Bottom Ash Production Rates For Model 1000 Megawatt Power Plants

	Cyclone Furnace		Dry-Bottom Pulverized Coal Furnace	
	Short Tons/Day	Short Tons/Year	Short Tons/Day	Short Tons/Year
Bottom Ash	145-390	51,000-140,000	38-110	14,000- 40,000
Fly Ash	47-140	17,000- 50,000	152-440	56,000-160,000

Source: Ref. 5-23.

to settling ponds. Slurries can be dewatered and the solids disposed of in landfills, or utilized in the production of clay bricks, pozzolon cement, and asphalt. Some dry ash is being dumped into the coal mines from which the original coal was mined.

In summary, the total amount of ash produced at a coal-fired electric generating plant depends upon the kind of coal burned and the kind of boiler installed at the plant. Stoker type boilers emit the least amount of fly ash and the most bottom ash, while cyclone units produce the most bottom ash and pulverized coal units emit the most fly ash.

Combustion of natural gas and oil produces quantities of ash that are orders of magnitude smaller as compared with coal and, therefore, were not considered.

Fossil Fuels - Power Plant Survey

Background

A review of the diverse data on particulate emissions from generating plants led to a decision to gather data at the source, i.e., the electric generating plants. A comparison of this data with data in the literature is instructive.

A sample of 21 out of 153 fossil fuel electric generating plants was selected from a list of plants meeting New Source Performance Standards (provided by EPA, Region II). The selection protocol for the 21 plants was: one plant from each state represented on the master list of NSPS plants; the first listed plant under each state (alphabetically ordered); and elimination of the first listed or second listed plant, etc., if problems were presented that could not be overcome (e.g., listed as being closed, listed under a different name or location).

Electric generating capacities of the selected power plants are presented in Table 5-38. As the table shows, electric generating stations are often composed of several generating units. Most, but not all units, are attached to some kind of particulate control device. Often 2 smaller units or more will share a control device. The generating capacity of most units is below 200 MW while many plants are in the range of 100 to 500 MW.

Control Device Utilization

Particulate emissions control varied among the power plants surveyed. Some plants have particulate control devices for each generating unit; some use only one device, and other plants employ combinations of different kinds of devices to process the flue gas stream(s) from one or several generating units.

Fossil Fuels - Power Plant Survey

Background

A review of the diverse data on particulate emissions from generating plants led to a decision to gather data at the source, i.e., the electric generating plants. A comparison of this data with data in the literature is instructive.

A sample of 21 out of 153 fossil fuel electric generating plants was selected from a list of plants meeting New Source Performance Standards (provided by EPA, Region II). The selection protocol for the 21 plants was: one plant from each state represented on the master list of NSPS plants; the first listed plant under each state (alphabetically ordered); and elimination of the first listed or second listed plant, etc., if problems were presented that could not be overcome (e.g., listed as being closed, listed under a different name or location).

Electric generating capacities of the selected power plants are presented in Table 5-38. As the table shows, electric generating stations are often composed of several generating units. Most, but not all units, are attached to some kind of particulate control device. Often 2 smaller units or more will share a control device. The generating capacity of most units is below 200 MW while many plants are in the range of 100 to 500 MW.

Control Device Utilization

Particulate emissions control varied among the power plants surveyed. Some plants have particulate control devices for each generating unit; some use only one device, and other plants employ combinations of different kinds of devices to process the flue gas stream(s) from one or several generating units.

TABLE 5-38

Electric Generating Station Survey[a] - Operational Data

Fuel	Generating Capacity (MWe)[b]	
	Plant	Unit(s)
Coal	13.5	0.072 0.025 0.035
Coal	25	25
Oil	120	120
Coal	134	17 26 91
Coal	200	75 93
Nat. Gas	230	115 115
Coal	232	44 44 69 75
Coal & Oil	280	27 35 62 156
Coal	330	110 110 110
Coal & Oil	340	87 89 162
Coal	358	179 179
Oil	1466	386[c]
Coal	483	180 303
Coal	492	69 71 352
Coal	496	190 306
Coal	652	330 322
Oil & Nat. Gas	951	100 102 102 287 360
Coal & Nat. Gas	1240	515 515 185 25
Coal & Oil	1310	340 340 640
Oil	1372	69 69 113 239 882
Coal	1452	800 650

---

[a] States represented: ND, OH, NM, MO, CO, OK, MT, NV, PA, NB, MN, AK, AZ, KS, NY, CA, VA, LA, FL, DE, MD.
Total plants - 21, Total Units - 57.

[b] Plant capacities may not equal the sum of the unit capacities due to rounding errors or conflicting data.

[c] Only this one unit is in compliance with NSPS, thus other unit capacities are not presented.

The frequency of use of the different types of control devices employed at the surveyed plants are given in Table 5-16. The coal-fired electric generating units have the most control devices installed. Natural gas-fired plants surveyed used no controls. Only some of the oil-fired plants utilized controls. ESPs are employed nearly 3 times more frequently than the next most commonly used kind of device, i.e., the scrubber. Baghouses and mechanical dust collectors are used the least.

Control Device Evaluation

The four parameters of principal importance in comparing particulate control devices are particulate collection efficiency, energy required by the device for operation, liquid and/or solid residuals generated by the device, and device cost (installation and operating). These parameters are discussed separately.

Particulate Collection Efficiency.

Table 5-39 presents the particulate collection efficiencies for control devices employed at the survyed plants. It can be seen that, for coal-fired plants, ESP efficiencies are quite high, averaging 97.9%. In fact, all but two of the 17 units exhibited efficiencies of 98% or better. Baghouse efficiencies averaged higher than ESPs, but only three coal-fired units employed baghouses, thus limiting the usefulness of a comparison. Scrubbers used at coal-fired units vary widely in efficiency, but in general they appear to be less efficient than either ESPs or baghouses.

Energy Utilization

It is difficult to compare energy use of control technologies because of the number of variables involved. Kind and size of the control device, boiler and plant specifications, age of the control

TABLE 5-39

Control Device Efficiencies - Power Plant Survey

Fuel	Parameter	Control Device ESP	 Scrubber	 Baghouse	 Mech. Coll.
Coal	Device Efficiencies (individual)	98-99%	84%	99.8%	30%
		98-99%	84%	99.9%	83%
		98-99%	90-99%	99.8%	
		98-99%	90-99%		
		98-99%	90-99%		
		99.5-99.9%	90%		
		99.5-99.9%	96%		
		90%	98%		
		90%	98%		
		98.6%			
		98%			
		99.6%			
		99.6%			
		99.6%			
		99.6%			
		99.2%			
		98%			
	No. of Devices	17	9	3	2
	Av. Efficiency[a]	97.9%	92.6%	99.8%	—
Oil	Device Efficiencies (individual)	+99%			90%
		80%[b]			
		80%[b]			
		80%[b]			
		80%[b]			
	No. of Devices	5	0	0	1
	Av. Efficiency	c	—	—	—
Coal & Oil	Device Efficiencies (individual)	98.6%	80%		92%
		97.8-99.8%			
		98%			
	No. of Devices	3	1	0	1
	Av. Efficiency	98.5%	—	—	—
All	No. of Devices	25[d]	10	3	1[e]

---

a. When a range is given for a unit efficiency, the midpoint of the range is used in the calculation of the average efficiency.

b. These units were constructed in the 1940's.

c. A meaningful average cannot be obtained for the units, since the four units with 80% efficiencies are very old and thus do not represent current designs.

d. One ESP in use at a coal-fired plant had no associated efficiency, thus the total number of ESPs in use equals 26.

e. One mechanical collector in use at a coal and oil fired plant had no associated efficiency, thus the total number of mechanical collectors in use equals 2.

device, mineral matter and heating value of the coal, and MW capacity of the plant are some of the variables involved in assessing the amount of energy used by a control device at an electric generating unit.

Most of the plant representatives at the 21 electric generating plants surveyed could not identify the amount of energy (usually in the form of electricity) consumed by the particulate control devices used at the plant. Energy consumption data is often not collected and hence is not known by those operating the plants. It is believed that this reflects the unimportance with which this factor is regarded. The lack of data available from plants surveyed is illustrated in Table 5-40, which presents data pertinent to control device operations.

Residuals

The amount of solid residuals produced annually by selected power plants is presented in Table 5-40. Fly ash collection data were obtained for one third of the power plants surveyed. Since only three plants that yielded fly ash employed a single type of control device, comparison of residuals produced by different devices is impossible.

In general, the amounts of ash (fly and bottom) produced depends upon the ash content of the fuel and the kind of boiler installed at the plant. Generally Stoker type boilers emit the smallest proportion of fly ash, pulverized coal units produced the most fly ash.

Costs

About one-half of the plants surveyed were unable to provide cost data. The data that was obtained does not lend itself readily to comparison because sizes and kinds of control technologies vary

TABLE 5-40

Particulate Control Device Data - Power Plant Survey

Generation Station		Control Device				
Fuel	Capacity (MWe)	No./Type[c]	Energy Use (MWe)[a]	Residuals (tons/y)[f] Fly Ash	Bottom Ash	Total
Coal	13.5	(1) ESP	0.67	b	b	b
	232	(4) ESP	6	b	b	38,235
	483	(2) ESP	b	20,440	81,760	102,200
	496	(2) ESP	b	137,445	2,805	140,250
	652	(2) ESP	b	233,000	117,000	350,000
	1240	(4) ESP	b	b	b	b
	330	(3) WS	22.5	b	b	b
	358	(2) WS	11-12	b	b	b
	25	(1) MC	b	b	b	b
	134	(1) ESP & (1) FF	b	249,480	47,520	297,000
	200	(1) ESP & (1) WS	b	b	b	b
	492	(1) WS & (1) FF	b	25,500	3,825	29,325
	1450	(1) ESP & (1) WS	43.5	b	b	892,500[g]
Oil	386	(1) ESP	b	b	b	b
	1372	(4) ESP & (1) MC	0.018[d]	b	b	b
Coal & Oil	280	(1) ESP & (1) MC	b	16,320	4,080	20,400
	340	(1) ESP & (1) MC	b	22,058[e]	4,845[e]	26,903
	1310	(1) ESP & (1) WS	b	b	b	263,925
Natural Gas	230	None	—	—	0.05	0.05

---

a. Energy use is the total for all devices.
b. Data is inaccurate or not available.
c. ESP - Electrostatic Precipitator, WS - Wet Scrubber, FF - Fabric Filter (Baghouse), MC - Mechanical Collector.
d. Figure reported by plant superintendent. Accuracy appears questionable.
e. Median value of ranges given: fly ash, 18,615-25,500; bottom ash, 4,590-5,100.
f. Assumes a standard operating schedule of 70 percent.
g. Sludge.

considerably with the characteristics of the fuel burned and the size of the electric generating plant. In addition, data was not available on the waste gas stream processed by a single device when multiple devices were in use at a given plant. This is important because the type and capacity of device required, and its subsequent cost, is totally dependent on the waste stream characteristics (e.g., the flow rate, volume, temperature, dust loading).

The capital costs data obtained in the survey is presented in Table 5-41. Five of the seven plants presented employed a single type of device, although two of those used two devices. The capital costs for installing these device types , per MWe of station capacity, was calculated and is given in the final column. Capital cost figures are presented primarily as an illustration since the data does not readily lend itself to cost comparisons.

Comparison of Survey and Literature Data

Efficiency - Baghouses exhibit the highest collection efficiencies, although they are employed the least in our sample. ESPs are utilized the most and have efficiencies near that of baghouses. Scrubbers tend to be less efficient than either ESPs or baghouses. The literature and data on control devices for fossil-fueled power plants available tend to substantiate the above findings.

Energy Use - The information gathered in the survey was not sufficient to make comparisons between the kinds of control devices and the amounts of energy used by each device.

Residuals - No comparison with the literature were possible for residuals because of the limited amount of data collected in the survey.

Costs - Again no comparisons with the literature on the subject are possible because of the lack of comprehensive data available through the survey.

TABLE 5-41

Particulate Control Device Costs - Power Plant Survey

Generating Station		Control Device			
Fuel	Capacity (MWe)	Type[c]	Date Installed	Capital Costs (1978 dollars)	
				Total	$/MWe
Coal	13.5	ESP	1976	1,725,000	127,800
	134	ESP	1973	2,850,000	a
		FF	1978	2,300,000	a
	492	FF	1978	6,000,000	a
		FF	1978	6,000,000	a
		WS	1973	5,800,000	a
	496	ESP	1975	9,600,000	b
		ESP	1976	13,800,000	b
		Combined		22,400,000	45,200
	652	ESP (2)	1976	10,350,000	15,900
	1450	WS	1973	69,000,000	47,600
Oil	386	ESP	1973	1,467,000	3,800

---

a. Determinations cannot be made for combinations of devices.
b. Costs combined to yield a total ESP cost per MWe.
c. ESP - Electrostatic Precipitator, FF - Fabric Filter, WS - Wet Scrubber.

REFERENCES

II.5-1 40 CFR 60.43, Environmental Protection Agency. 1977.

II.5-2 Federal Register. Vol. 43. No. 170. August 31, 1979.

II.5-3 Bureau of Mines. Mineral Commodity Profiles. 1978.

II.5-4 U.S. Comptroller General. Report to Congress, U.S. Coal Development - Promises, Uncertainities. September 22, 1979.

II.5-5 U.S. Environmental Protection Agency. Industrial Environmental Research Laboratory. Source Assessment: Open Mining of Coal - State of the Art. September, 1978.

II.5-6 U.S. Environmental Protection Agency. Environmental Assessment of Coal Transportation, Interagency Energy/Environmental R&O Program Report. Cincinnati, Ohio, 1978.

II.5-7 U.S. Environmental Protection Agency. Source Assessment: Coal Storage Piles. Cincinnati, Ohio, 1978.

II.5-8 Beck, et al. Perturbations on the Natural Radiation Environment Due to the Utilization of Coal as an Energy Source. Department of Energy. Environmental Measures Laboratory. N.Y., N.Y., 1978.

II.5-9 U.S. Environmental Protection Agency. Radiological Quality of the Environment in the U.S., 1977. EPA 520/1-7-009, September, 1977.

II.5-10 Health Physics Society. 10th Midyear Topical Symposium. The Radiological Implications of Increased Coal Utilization. Troy, N.Y., 1976.

REFERENCES (cont'd)

II.5-11 Klein, *et al.* "Pathways of Thirty-Seven Trace Elements Through Coal-Fired Power Plants." *Environmental Science and Technology,* October, 1975.

II.5-12 Coles, *et al.* "Behavior of Natural Radionuclides in Western Coal Fired Power Plants." *Environmental Science and Technology*, April, 1978.

II.5-13 U.S. Environmental Protection Agency. *Analysis of Radioactive Contaminants in By-Products from Coal Fired Power Plant Operations.* Cincinnati, Ohio, 1978.

II.5-14 U.S. Environmental Protection Agency. Office of Radiation Programs. *Natural Radioactivity Contamination Problems.* EPA-520/4-77-015, 1978.

II.5-15 U.S. Environmental Protection Agency. Personal communication, Charles Amato, December, 1978.

II.5-16 Environmental Protection Research Institute. *Study of Electrostatic Precipitators Installed on Oil-Fired Boilers.* Palo Alto, Ca. 1978.

II.5-17 U.S. Environmental Protection Agency. Office of Air Quality Planning and Standards. *Electric Utility Steam Generating Units. Background Information for Proposed Particulate Matter Emission Standards.* Research Triangle Park, N.C., 1978.

II.5-18 Southern Research Institute. *A Survey of Technical Information Related to Fine Particle Control*. Birmingham, Al., 1975.

B39/7

REFERENCES (cont'd)

II.5-19 Electric Power Research Institute. Economic Evaluation of Fabric Filtration Versus Electrostatic Precipitation for Ultrahigh Particulate Collection Efficiency. Palo Alto, CA., 1978.

II.5-20 Meteorological Research, Inc. Determination of the Fractional Efficiency, Opacity Characteristics, Engineering and Economic Aspects of a Fabric Filter Operating on a Utility Boiler, EPRI FF-297, MRI 76 FR-1411, November, 1976. Prepared for Electric Power Research Institute.

II.5-21 U.S. Environmental Protection Agency. Office of Air and Waste Management. Particulate and Sulfur Dioxide Emission Control Costs for Large Coal-Fired Boilers. Research Triangle Park, NC., 1978.

II.5-22 The McIlvaine Scrubber Manual. Vol. 1. Chapter IV. Northbrook, Ill.: The McIlvaine Company , 1974.

II.5-23 Electric Power Research Institute. The Impact of RCRA (PL 94-580) on Utility Solid Wastes. Palo Alto, CA., 1978.